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Contract for Supply and Services Canada

DETERMINATION OF THE LIKELIHOOD OF THE INFLAMMATION OF METHANE ATMOSPHERES AND/OR COAL DUST LAYERS BY COMPONENTS OF MOBILE DIESEL POWERED EQUIPMENT WHICH ARE SUBJECT TO FRICTIONAL OR IMPACT HEATING.

Principal Investigator: N.G. Eley, P.Eng.
Associate Professor
Dept. Mechanical Engineering
University of British Columbi

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Associate Professor
Department of Mechanical Engineering
University of British Columbia

Research Assistant: D. Singh

March 15, 1979

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Principal Investigator:

Norman G. Eley P.Eng.
Department of Mechanical Engineering
University of British Columbia

FOREWORD

This report was prepared by N.G. Eley with assistance from D. Singh, Department of Mechanical Engineering, University of British Columbia, under Contract No. 03SU.23440-7.9104 issued by Supply and Services Canada. It was administered under the technical direction of the Canadian Explosive Atmosphere Laboratory of Energy Mines and Resources Canada, with Mr. Paul Mogan acting as the Scientific Authority.

The period of this contract was April 1, 1978 through March 31, 1979.

STATEMENT OF WORK

To investigate the potential risk of inflammation of oily coal dust layers and/or methane atmospheres by frictional heating in impact of:

(a) Normal use of the starter engagement system used on mobile diesel powered mining equipment.

(b) Abnormal use of the starter

i) in attempting to start a seized engine

ii) in attempting to start a running engine

(c) Normal operation of drum and disc brakes in maximum underground gradients.

(d) Abnormal operation of drum and disc brakes (dragging pad or shoe)

(e) Normal clutch operation

(f) Abnormal clutch operation

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INTRODUCTION

Safety in the working environment has achieved a laudable improvement in all industries during the past ten years. It has always been a matter of great concern to those engaged in mining and in particular as related to coal mining. With the introduction of mechanization to mines the environmental criteria have been changing as it has proceeded. Mechanization in coal mines has been steady and is still developing, at the mining face and in the transportation of men and materials. The provision of power in coal mines has always been a significant problem, and over the last forty years there has been an increase in the use of diesel powered equipment in all mining. The experience has been good. Productivity has been improved substantially and the production costs have been reduced accordingly. Regulations have been developed in most countries to control the use of diesel power, to deal with safety hazards inherent in their use in mining environments. In general, these are related to air requirements for the engine, and explosion proofing. It is the author's observation that the regulations may be unduly restrictive, but have led to an experience base which has resulted in no reported accidents relating to diesel engines, and explosions in mines. While statistics are not completely available for all countries, all sources consulted yielded no reports of accidents attributable to the diesel units operation. It is quite obvious that coal mining has over the years suffered from the "disaster syndrome" since published news in articles relate only to the accidents. It is understandable why safety measures have been so subject to "overkill". The prejudice against diesel units underground has gradually disappeared in general, however, there is still a good deal of reaction against their use in specific areas in North America. This report will deal with only two areas of risk in diesel engine operation.

i) Risk due to impact heating.

ii) Risk due to friction heating.

The first area of risk is confined to starter systems, and the second to wheel and drive line brakes, and friction clutches. An overview of the use of the equipment, regulations governing its use, the research background on which the regulations are based, and an examination of the component characteristics follows.

THE USE OF DIESEL ENGINES IN COAL MINES

Diesel Engines have been used in coal mines since the late 1930's. Their use has been patterned by the mining method and the country. The use may be characterized by those used to power monorail locomotives, tracked locomotives, rubber tired transport vehicles, and rubber tired haulage vehicles.

The European coal mines have leaned to monorail systems with rope or deisel haulage for face operations, and deisel locomotives for men and material transport. The British experience has been to use tracked diesel engined locomotives mainly for man transport where workings are under sea. Rope and belt conveyors are very common. In Canada the usage has followed the British experience generally in East Coast mines, and newer installations are tending toward rubber tired diesel powered vehicles. With the advent of "hydraulic mining" the whole concept of product transportation has changed dramatically. In such mines diesel powered equipment is used for man and material transport and development. With the advent of hydraulic mining the dust hazard is almost non-existent.

The main concerns in using diesel equipment underground are explosion and ventilation. These are related to the heat produced in exhaust, or on surfaces of the engine, and the contamination of the air by exhaust gases. Control of

International regulations for Diesel engines in coal mines (underground)

Country	Australia (New South Wales)	Federal Republic of Germany		France	Great Britain and Canada	South Africa	USSR		USA	
Currently valid regulations	Regulations of N.S.W. Mines Department	"Constructional prescriptions for mining locomotives" of LOBA Dortmund of 11. 6. 54 and VDE 0170	Proposed a) "Constructional prescription for tractors" b) "Underground application of rail independent not force-guided Diesel vehicles" of LOBA Dortmund of 1975	Explosion risk mines no. 1207 of Sept. 1973	Test agreement no. 12 (November 1969) of the Ministry of Technology Dept. Safety and Health	"Specification for Diesel engines applied in fire risk mines" SABS 868 – 1967	"Manufacturing regulations for transport vehicles driven by Diesel engines in coal and slate mines" of 1974		Diesel equipment for coal mines and explosive atmosphere mines" of the Federal State Rules Schedule 31	
Diesel engine test authority		TÜV Essen (authorized as recognized specialists of LOBA, Dortmund)		Cerchard	"The safety in Mines Research Establishment, Field Laboratories" Harpur Hill Buxton	South African Bureau of Standards	Institute MAK N II or Institute WOST N II		Bureau of Mines, Pittsburgh	
Fourstrocke Diesel engine D = direct injection i = indirect injection W = watercooled	D, i, W	D, i, W	i, W	Not specified	D, i, W	Fourstroke Diesel engine, W	Fourstroke Diesel engine, W		Not specified	
max. permitted exhaust gas emission for a new engine (values in brackets require withdrawal from service)							Before gas cleaning	After gas cleaning	$CO = NO_x$ = 8g/Psh	At 1 +/– 0,1 % methane addition
CO (ppm)	(1500)	500 (1200)	500 (1200)	Not specified	(2000)	(2000)	2000 (2000)	800 (800)	~ 1500	3000
NO (ppm)			700							
NO_x (ppm)	(1000)		750		(1000)	(1000)	700 (700)		~ 900	
Flame pathlenght (mm) on cylinder head for the connection of inlet air and exhaust gas manifold	12,7	10	10	25,4	12,7	25,4	13		At discretion of Bureau of Mines	
Max. permitted surface temperature (° C)	149	200	150	200	135	205	150		149	
inlet air and exhaust gas manifolds pressure resistance in (bar)	8,75	8	10	3	10,5	8,6	8		8,6	
Experimental test of flame proofing of the engine incl. inlet air	Not specified		Not specified	Not specified	Hydraulic test for manifolds	Explosion test				
Aluminium alloy for external engine parts			Permittend only with restrictions		None, unless surface treated	Not specified	None, unless surface treated		Not on moving parts, on non moving parts Mg content < 7 %	
Starting equipment	Electric start not allowed	Electric allowed if flame proofed	Electric start not allowed		Electric start not allowed	According to SABS 314 or SABS 549 if electric	Explosion proof		Compressed air	
Narrow V-belt	Antistatic and fire resistant									
Fan material	No iron	Not specified							Not iron	
Crankcase ventilation	Not specified		With non return valve	Not specified	With non return valve				Not specified	

— Not attainable with the D 916 series

TABLE 1

the heat produced is necessary due to the explosion hazard associated with methane and coal dust. Methane is released in all coal workings, as a natural phenomena, and obviously coal dust is a product of mining face activity. The explosion hazard is eliminated by providing adequate "make up" for the engine breathing, suitable ventilation, to safety regulations and "explosion proofing" the engine to specific regulations.

REGULATIONS GOVERNING THE USE OF DIESEL ENGINES IN COAL MINES

Table 1 is a broad outline regarding the regulations relating to the use of diesel engines in coal mines for all countries. It is apparent from this chart that there are areas of disagreement in the area of maximum surface temperature permitted, 135°C through to 200°C. This indicates that the research evidence is not well established or as convincing as it should be. Statistics does not appear to be available to compare these jurisdictions as far as accident performance. This chart does not cover other essential features such as additional ventilation capacity.

Canadian Regulations

These are based and almost identical to those published in the National Coal Board's Testing Memorandum #12 (TM12). Since this report is concerned with starters' and brakes, it is of interest to cite the regulations.

Starters: - no regulations, except if considered a part of the engine assembly, the surface temperature must not exceed 150°C. (302°F)

Brakes: - "Braking systems must be designed to eliminate or minimize, so far as is practicable the generation, any part of the system, of temperatures capable of igniting combustible material likely to be present in the vicinity of that point. Brake blocks or linings must be of a type designed to minimize incendive sparking by frictional contact."

Clearly this does not spell out a temperature and the research work to date while showing some conditions where methane-air, coal dust explosions will take place, the relationship between experimental conditions and mine operation are difficult to visualize.

U.S. Regulations Current

The U.S. Regulations Part 31, calls only for "adequate brakes". The new draft regulations Part 31, Sub Chapter E, Chapter I, Title 30 calls for specific performance tests on brakes but in neither case are there specific regulations related to concern about starter impact energy or frictional heating as potential explosion hazards.

Diesel Powered Units used in Coal Mines

Since Canadian and British Regulations are common the following statements regarding usage relate to U.K. and Canadian usage. The use of diesels in U.S. coal mines is not approved usage as the regulations have applied only to "Gassy Non-Coal Mines". The United Mine Workers of America have stoutly resisted the development and use of diesels in union coal mines.

British Coal Mines

Most diesel powered units used in U.K. coal mines are installed in locomotives, rubber tired vehicles and monorail diesels are not used as extensively. There are 608 locomotives in use with diesel engines of 22 H.P. to 100 H.P. as the drive unit, in underground workings. Another 380 vehicles of various types are diesel powered. Some of the locomotives have been in service for twenty plus years and are used with exposed air-cooled exhaust manifolds. The manifolds reach temperature ranges of 400-600^{o}C in normal operation, so some experience has been obtained at this temperature level. Apparently trouble has been experience further down the exhaust pipe where coal dust-oil mixtures occasionally take fire.

Typical locomotive specifications (U.K.)

A typical pair of modern locomotives for use in coal mines are the 102 BHP 0.6.0 Hudswell Badger and the 100 HP Hunslet. Details are illustrated in brochures appended. They are flameproofed units powered by 6 LW Gardner Diesel Engines for the Hudswell Badger, and a 100 HP Perkins for the Hunslet. The starters used are compressed air type with Bendix clutch drive. The brakes are pneumatically operated cast iron brake blocks to each wheel tread of high tensile steel. About 300 of those locomotives in service are in the 100 HP class.(1)

Typical Tracked Vehicles

The most used vehicles of the rubber tired type used in U.K. mines are as follows: Hunslet M-25-M40-M60-M-90. These are powered by 25, 40, 60, 90 HP. Perkins diesel engines with direct fuel ejection are to flameproof specifications. Their comparative brake and starting arrangements are as follows:

Vehicle	Engine	Starter	Brakes
Hunslet MT 25	25 HP Perkins	Spring or air	External contracting band brake - hand operated
Hunslet MT 40	40 HP Perkins	Spring or air	Hydrostatic brakes and drive
Hunslet MT 60	60 HP Perkins 6-354	Air Spring	Hyrdostatic brakes
Hunslet MT 90	90 HP Perkins	Air	Hydrostatic brakes

Also available are European versions of the Wagner and Eimco vehicles. The general specifications are similar except Eimco 913 and Wagner Becorit UT 45. The latter machine employs Hydraulic starters.

Canadian Coal Mines (Tables 2 and 3)

The locations cited are Pugwash, N.S. and Sparwood, B.C. These are two of the larger coal mining areas. It is of interest to note that the Province of Alberta appears to disallow the use of diesel equipment in coal mines. This is hearsay information. The equipment mentioned here will represent a reasonably

TABLE 2: SUMMARY OF DIESEL HORSEPOWER USED UNDERGROUND AT PUGWASH, NOVA SCOTIA.

No. of units	Make and model	Engine horsepower per unit	Total horsepower	Horsepower used for tramming only (intermittent)	Horsepower used for working (continuous)
3	Terex 13 UOT haulers.	160	480	-	480
2	Caterpillar 966C front-end loaders.	170	340	-	340
1	Euclid L-20 front-end loader.	152	152	-	152
1	Rogers drill.....	80	80	80	-
1	Joy drill.....	107	107	107	-
1	Giraffe 45-ft platform on Chevrolet truck with auxiliary engine.	97 22	119	97	22
1	Giraffe 40-ft platform on dumptor with auxiliary engine.	107 25	132	107	25
1	Wabco 2500 undercutter with auxiliary engine.	81	81	81	-
1	Joy 15RU undercutter with auxiliary engine.	107	107	107	-
1	Ford 5000 tractor....	72	72	-	72
1	Champ 350 HLD tractor	140	140	-	140
1	Giraffe 70-ft platform on Chevrolet truck with auxiliary engine.	195 25	220	195	25
3	Massey Ferguson 135 tractors.	39	117	-	117
1	Caterpillar D336.....	300	300	-	-
Total: 19	-	-	2,447	774	1,673

SOURCE: Table 1, "Canadian Experience Using Diesels in Underground Coal Mines," by H. Zorychta, in Proceedings of the Symposium on the Use of Diesel-Powered Equipment in Underground Mining, Pittsburg, Pa., January 30-31, 1973.

TABLE 3

SUMMARY OF DIESEL POWERED UNDERGROUND MINING EQUIPMENT
AT KAISER RESOURCES, SPARWOOD B.C.

3	Hunslet Vehicles MT60 Platform
3	Eimco Model 975 Platform Vehicle Pipe Truck
2	Eimco Model 913 - LHD Units
1	Eimco Model 911 - LHD
*1	Wagner ST-5A - LHD
*1	Scharf Model No. 315 Monorail Engine

* Not in service 1979

All vehicles are equipped with air starters.
All vehicles are equipped with dry disc brakes except the Hunslet equipment and monorail.
Hunslet vehicles are equipped with hydrostatic drive, and the Scharf Monorail employs track brakes.

road spectrum of the equipment utilization in Canada. Pugwash, N.S. (from Canadian Experience Using Diesel in Coal Mines," H. Zorychta: Proceedings Symposium on Use of Diesel Engine Equipment in Underground Coal Mining).

It is noted that at Pugwash there is a wide variety of equipment, and the range of horsepower runs from 25 through 300. Some of this equipment may be equipped with mechanical disc clutches. They would be only on older equipment and applied to those in the under 100 HP class.

Sparwood, B.C. Kaiser Resources

This mine relies exclusively on diesel power for man-material transport, and in the development areas of the underground. Their active mining areas are "hydraulically mined," so diesel equipment is used for movement of men and material only. The mine has little coal dust hazard in the mining area. In the areas of development, hazards relative to coal dust and methane are normal. Observations at the mine, and discussions with their underground engineering personnel indicate general satisfaction with diesel powered underground equipment. The concern about maintenance procedures and daily equipment checks was most obvious. Their safety record regarding use of their diesel powered equipment has been excellent. No equipment based accidents has been reported. Their equipment list is shown in Table 3 with data related to starters and brakes.

Clutched Vehicles

In the foregoing some reference to clutched vehicles was made. It is considered highly unlikely that there will be any new underground deisel equipment with friction clutches. Frequency of service, and control problems in gradients, coupled with operator skill and reticence to drive "clutched" vehicles have all led to fewer vehicles equipped with mechanical clutches being used underground. A vehicle developed by Hunselt, (Appendix I) using the Land Rover is completely flameproofed. Their specifications are limited on their brochure, however this

is the only vehicle available which may be obtained with a standard dry disc clutch. It is not specifically recommended for underground coal mining applications.

Monorail Equipment

One of the major manufacturers of monorail equipment for coal mines is the Scharf Company, Ham. Germany. They have developed a unit which has been exhaustively tested at the West German Coal Research Institutes. They are of the 80-100 HP class in terms of dieselpower, and the newer explosion proof systems are equipped with MWM water cooled Diesel engines. Their main use to date has been in Europe, but the units are gaining reasonable acceptance in North America.

SUMMARY OF RANGE OF DIESEL COAL MINING EQUIPMENT

1979. Today the majority of the equipment used in underground coal mines can be typified as follows:

Locomotives - 100 HP Diesel Engine maximum
Hydraulic drive
Cast iron brake blocks - air or hydraulically operated vehicle
Spring air starters

Man & Material Vehicles - 100 HP Diesel Engine maximum
Hydrostatic or Hydraulic Drive
Pneumatic hydraulic - hydrostatic braking
Air-spring starters

Load Haul and Dump Vehicles - Max. 150 HP Diesel Engine
Hydraulically operated tire axle
Hydraulic disc brakes

Monorail Transport - Max. 100 HP Diesel Engine
Cast iron track brakes
Mechanically or hydraulically operated
Air starters

1980-90. The main development in underground vehicles appears to be in the direction of the LHD (Load, Haul and Dump) vehicle and adaptations of this design for man-material hauling. Large tires, higher power and higher load capacity will be the main objectives.

The main advantages accorded to the use of diesel powered vehicles in coal mines have been cited as;

1) Flexible - much more so than electric locomotive or rope haulage.

2) Diesel can operate in intake or return air.

3) Accident rate much lower, 25% of that encountered on rope haulage.

4) More economical than current haulage.

5) Increased productivity.

The LHD type vehicle will supplant the locomotive in time since there are grade limitations and indeed cost limitations. For a given capacity more can be obtained from a LHD type vehicle than a locomotive. The intermediate flat top vehicles will still serve a useful purpose. It's difficult to comment on the future of monorail diesels. Certainly in Europe when the mining methods are quite different, and with long experience and use I would expect this to continue and the monorail diesel use will grow as the mining industry grows. It is likely that European coal workings will be less competitive as time goes on, thus pressure on higher productivity will be great.

Diesel Engines for Underground Coal Mining Equipment

There is little question that the choice of diesel engines for underground coal mines is extremely limited, and will become less as time goes on. Approved for use in U.K. Coal Mines are the following flameproofed engines:

Hunslet MT 60 - Perkins 4.236 direct injection

Hunslet MT 90 - Perkins 6.354 direct injection

Becorit 90 HP - MWM 6.916 indirect injection

In Canada added to this are flameproofed versions of the:

Caterpillar 3304 and 3306 indirect injection; and

MWM 6.916 indirect injection

In discussions with National Coal Board representatives it would appear that Perkin's engines are obsolete (Perkin's view) and there is some doubt about continuing supply. Since they are direct injection engines their ventilation requirement is extremely high and this mitigates against their continued use. Gardner Deisel is no longer producing a cast iron block, and head of any type. It would appear that the all aluminum block and lead are not very easily accepted due to the aluminum-steel impact exposure problem. This is unlikely to change. Gardner has recently been purchased by Hawker Siddely. They and Perkins are not likely to continue to be interested in the small volume available to them from the coal mining market.

The engines which suit the newer generation of vehicles are MWM and Caterpillar. The series used and approved for coal mining are water cooled indirect injection four cycle engines. They have good reliability records and have excellent service available in North America. The economic changes of recent date seem to indicate that the Caterpillar Engine is likely to be a standard since German Engines are getting very expensive. There is no doubt that indirect injection engines will be required since as a class their emmission levels are appropriate to the current standards.

The Ideal Underground Coal Mining Vehicle

It is interesting to speculate in the area of what constitutes an ideal solution to the problem which must satisfy

(i) Government Regulations for Health and Safety

(ii) Productivity Capability

(iii) Low Maintenance

(iv) Fuel Economy

(v) Original Cost

(vi) Service ability

Broadly stated the author's outline of the ideal vehicle for underground coal mining is as follows:

Engine: 4 cycle water cooled naturally aspirated indirect injection diesel engine.

Starter: "Nova" type starter.

Brakes: Wet disc type.

Hydraulic System: Dual pump system, one for operating the external requirements where hoses required. The other for all other internal systems. The former filled with fire resistant fluid, the latter with good grade of hydraulic oil.

To these requirements add the usual requirements of regulations such as TM 12. At any rate this "ideal vehicle" would cause no concern relating to starter impact energy or brake heating.

SAFETY IN THE COAL MINE

The Mine as an Operating System

A mine is a set of shafts and/or tunnels to provide access to valuable natural materials for their economic removal. Provision must be made for the removal of the ore from the country rock and then from the mine. This system is akin to any other system requiring man, equipment, and materials. The design or physical layout of the mine is usually dependent on the geological reference points, and a very specific knowledge of the faults and geology. The development phase is the provision of removal gear for men material and ore, and the provision of adequate ventilation such that all environmental needs are provided for men and equipment.

Generally the methods of production removal in a coal mine are cutting heads at face, and conveyance by belt or bucket to the outside with intermediate elevators or dumps. In mechanized systems the men working in the mine are continually monitoring the operation moving material, ore, or manpower, in or out of the workings.

Use of Diesel Equipment in Coal Mines

As previously stated, diesels have had a forty year history in coal mining. They have been usually used in main tunnels, and occasionally in blind tunnels, usually for man and material transport. The locomotives trucks or monorails are almost always outside the mine at start-up. Thus problems associated with start-up are all in the open air and not in the mine. Most vehicles are fueled outside the mine. All vehicles are geared down very substantially so that the top speed capability is seldom more than 10 mph. Many have hydrostatic drive so have no external braking system. Due to the large gear reduction, engine braking is very good thus standard operation puts little reliance on the brakes except to bring the vehicle to a final halt. Most vehicles are equipped with fluid coupling,

orque converters, or some form of hydraulic drive, thus there are no friction clutches in use except in rare cases.

Thus if we can summarize the operating parameters in coal mining as related to starting and braking.

1. Almost all vehicles starting will take place outside the mine.
2. Most of the vehicles are geared down such that in normal operation the brake does not need to be used travelling down grade.
3. Vehicle speeds in the mine seldom if ever exceed 5 mph.

When you add the factor of adequate ventilation in the mine as the primary safety feature required in mine workings the question of explosive atmosphere does not appear to be relevant. Methane content in the mine atmospheres does not appear to be relevant. Methane content in the mine atmosphere is required to be constantly monitored, with evacuation proceeding at about one half the tolerance level.

When these operating characteristics are considered with the regulations the risk factor appears negligible.

Safety Performance

The use of diesels in coal mines has its hazards. The most common cause of accidents has been the driver. This is analogous to the case of automobiles and the public at large. With current regulations there is no recorded incident in a coal mine where a diesel engine has been the direct cause of an explosion. Since this is the main hazard that is being dealt with the record is a very good one.

It is a matter of record (Table 4) that coal mining is not as hazardous as we are led to believe. The following data is taken from source

Table 4

Fatal Accident Frequency Rate for Various Human Activities (FAFR)
Number of deaths per 10^8 hours of exposure.

Industrial Activities		Leisure Activities	
Chemical Industry	3.5	Staying at Home	3
British Industry	4	Travelling - bus	3
Steel Industry	8	- train	5
Fishing	35	- automobile	57
Coal Mining	40	Bicycling	96
Railway Shunters	45	Travelling by air	240
Construction Workers	67	Scooter driving	310
Air Crew	250	Motorcycling	660
Professional Boxers	7000	Canoeing	1000
Jockeys	50000	Mountain Climbing	4000

If 2500 hours is taken as an industrial working year and 40 years as a working life, then the FAFR for any particular risk is equivalent to the number of deaths expected from 1,000 men subjected to that risk for their entire working life.

Source: Gibson, S.B.: "The Quantitative Measurement of Process Safety," I. Chem. E. Symposium Series No. 49, pg. 8.

IMPACT HEATING IN DIESEL POWERED COAL MINING EQUIPMENT

Background

Approval authorities for diesel equipment for use in coal mines have not specified any regulations related to impact heating as a hazard. The obvious source of such heating is in the vehicle starter. Electric starters are banned from coal mines for obvious reasons. Thus all starters for deisel engines used in coal mines are driven mechanically, hydraulically, or pneumatically. The impact heating energy is that produced in engagement of the starter pinion with the ring gear. This potential hazard has long been recognized but there is no evidence at all that it has ever been a cause of an explosion in a mine.

Research Background

P. Morgan has summarized the hazard criteria as he sees them in his paper of February 1978 (3). He concludes that:

(i) Ignition of methane air by frictional rubbing requires an energy impact of at least .5I KW/CM^2 ($4HP/in^2$) or a surface temperature of 975°C for metal and 1250°C for non-metal parts. The presence of coal dust layers reduce the critical temperature to 150 - 220°C.

(ii) Pure impact of hardened steel parts may ignite methane air mixtures at an energy point of 24 kg/m (177 ft lbs).

Impact Energy as an Explosion Initiator

The Mogan report has searched the available literature quite well. It is concluded that methane-air mixture ignition can only take place if the surface temperature of a metallic surface exceeds 975°C or 1250°C for a non metallic surface, and energy inputs as previously suggested. The real systems are not specifically used in most experiments. I am very surprised that ignition tests have not been performed on brake Dynamometers. Where actual braking conditions could

simulated very easily and good quantitative measurements taken. This could establish practically what the laboratory experiments have established as a direction. Muller's work (4) concludes that a good deal of the research has looked into the matter of spark hazard and light metal sparks. Light metal sparks do not behave as steel sparks. He is critical of "close to reality" experiments that use drop or percussive weights. When these tests are conducted it may be the ignition produced is from a spark on the hot friction suface. Litman (5) has shown that rail versus wheel tests showed that sparks produced would not ignite methane air mixtures.

While the author draws the same general conclusions from the references (6) (7) (8) (9), it is difficult to see a strong resemblance in the mine operating circumstances to the experimental environment. If data is required for starters, starter units could be very easily tested under operating conditions, and perhaps approvals given. The reference work indicates that the methane-air mixture hazard is of no consequence since operating equipment will never attain temperatures cited. Regarding the coal dust problem the work of Hardy (10), Silver (11), Herzberg et al (12), gives some indication that 220^{o}C is a critical temperature for a layer of coal dust 12 mm thick, and 2-7 micron coal dust is hazardous in flowing air down to 160^{o}C. These results seem to verify the selection of values of surface temperature in the National Coal Board's TM12.

STARTING EQUIPMENT FOR DIESEL ENGINES

All engines used for coal mining equipment use power starters.

The starter motor is equipped with a pinion gear which meshes with a ring gear usually attached to the flywheel (Fig. 1). The force applied by the pinion gear rotates the crank shaft by means of the ring gear until the engine starts. There are two general types.

(i) pre-engaged - where the starter pinion is engaged with the ring gear before the pinion is rotated.

(ii) standard drive - where the starter pinion is pushed into engagement with the ring gear, and rotated simultaneously.

The drive mechanism is by pneumatic or hydraulic motor, or by a wound-up spring.

In North America almost all diesel starters used are of the pneumatic type.

State of the Art Manufactured Starters

As a base line for starter equipment it was deemed appropriate to use the equipment at Kaiser Resources as a model. Their underground diesel fleet at Sparwood consists of the vehicles listed in Table 3. The larger units are powered by Caterpillar 3304 and 3306 diesel engines as approved by the Energy Mines and Resources Canada in the vehicles. They also meet the standards and requirements of the Ministry of Mines and Petroleum Resources of B.C.

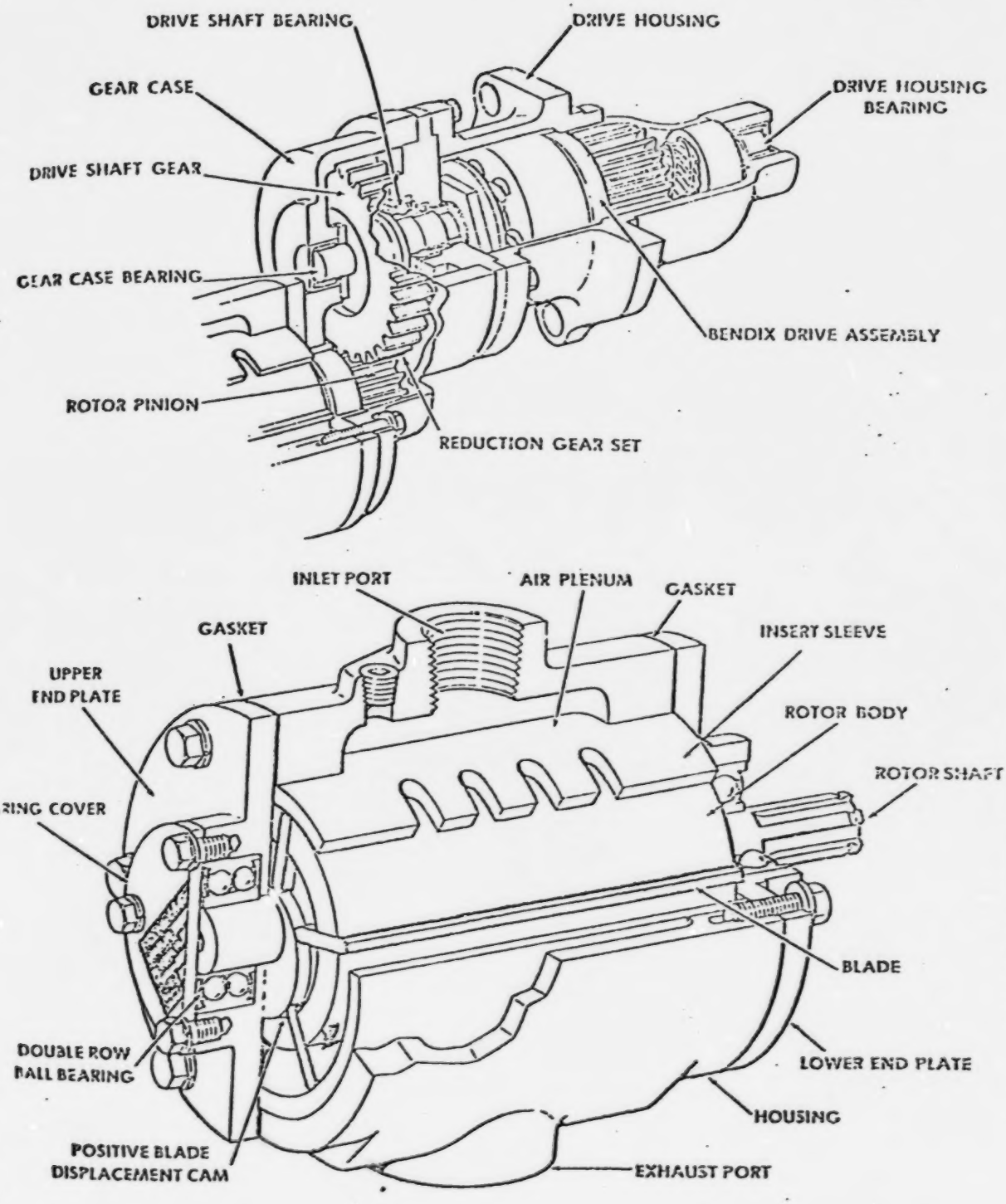
Starter Application

The largest diesel engine used in the Kaiser Resources Fleet is that installed in the Wagner Load Haul and Dump Vehicle. It is a Caterpillar 3306 series Engine with the following engine specifications:

Caterpillar Diesel 4 cycle Model 3306 - naturally aspirated.

USBM Schedule 31 Power Rating @ 2200 rpm (W/O fan) - 146 HP.

Bore and Stroke 4.75" x 6", 6 cylinders.



INTERNAL VIEW OF THE START MASTER AIR MOTOR

FIG. 1 TYPICAL AIR STARTER

Displacement - 638 cu in.

Water cooled.

engine is fitted with a pre-combustion chamber and is one of the most environ-tally "clean" available on the market.

Starter units for this engine can be obtained from a number of sources. se have been chosen for comparison purposes, and those chosen would account about 90% of those sold in North America.

The sources are: Canadian Ingersoll Rand

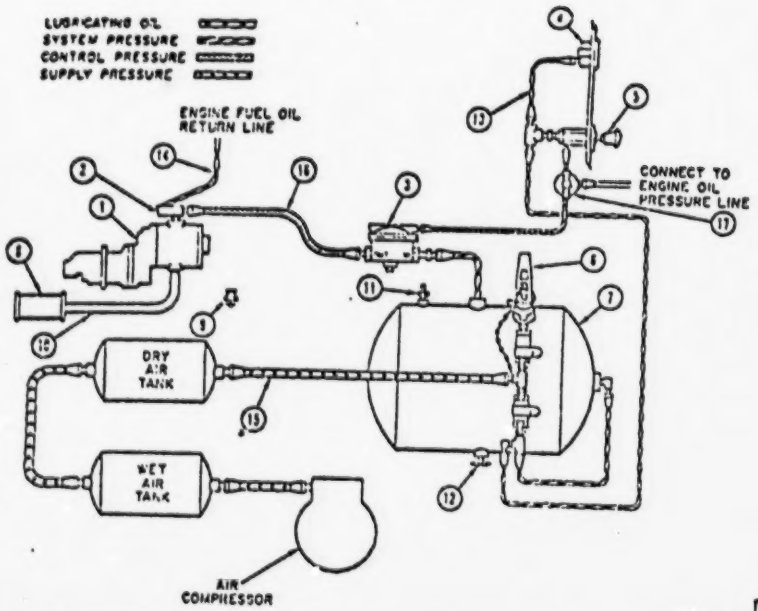
U.S. Bosch Corporation

Stanadyne/Hartford Divisions

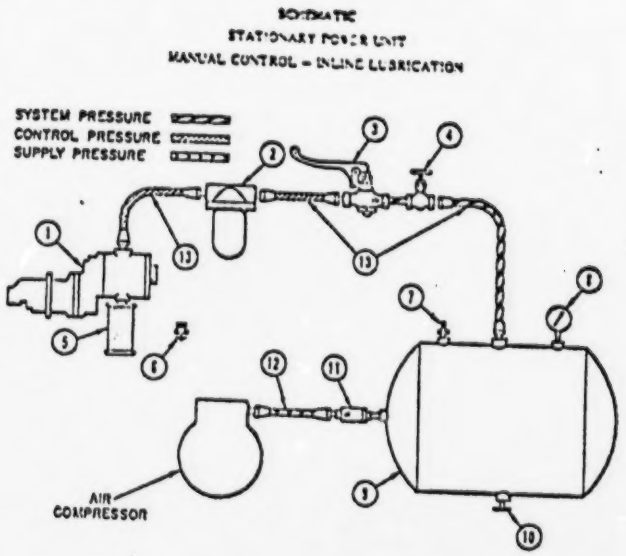
Starters

The air starter is an air motor which drives a pinion gear. The air supply usually from a receiver which is supplied by a compression which is driven by e main power plant. Fig. 2 is a sketch of a typical installation, Fig. 3 a pical air motor. The housing assembly is a cast aluminum rim sleeved unit. t provides a means of support for the other motor components and contains assages that direct the air flow without the starter. The rotor consists of a otor body attached to a steel shaft. Five rotor blades or vanes are mounted in lots in the rotor body, which is the rotary element of the motor. The endplates re similar and provide accommodation for the blade positioning cam and ball earings.

The motor is energized by supplying compressed air at 90-150 pounds per square inch to the inlet fitting. The pressurized air enters the inlet plenum and flows at high velocity through inlet slots in the housing sleeve. The air flow impinges in the rotor blades causing the rotor to turn. As the rotor turns the air trapped between the blades expands then discharges through the outlet slots into the exhaust plenum and out through the exhaust port.

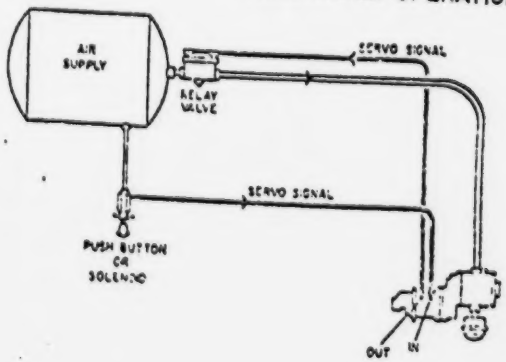


ITEM	DESCRIPTION	NPT SIZE	ITEM	DESCRIPTION	NPT SIZE
1	Start Master	1/8"-1"-1 1/4"	12	Drain Valve	1/4"
2	Start Master Lubricator	1"-1 9/16"	13	1/4" Hose, Aeroquip or Equal	
3	Relay Valve		14	1/4" Reinforced Rubber Hose	
4	Gauge 0-160 PSI	1/4"-1"	15	1/2" Hose, Aeroquip or Equal	
5	Control Valve	1/4"	16	1" Hose, Aeroquip or Equal	
6	Manifold Assy.	1/4"	17	Lockout Relay Valve	
7	Air Receiver				
8	Exhaust Muffler				
9	Exhaust Valve	1/4"-1/2"-1"			
10	1-1/2" ID Flexible Rubber Hose	1 1/4"			
11	Fill Valve	1 1/4"			
		1/8"			



ITEM	DESCRIPTION	NPT SIZE	ITEM	DESCRIPTION	NPT SIZE
1	Start Master	1/8"-1"-1 1/4"	9	Air Receiver	1/4"-1/2"-1"
2	Lubricator	1"	10	Drain Valve	1/4"
3	Control Valve	1"	11	Check Valve	1/2"
4	Globe Valve	1"	12	1/2" Hose, Aeroquip or Equal	
5	Exhaust Muffler	1"	13	1" Hose, Aeroquip or Equal	
6	Exhaust Valve	1 1/4"			
7	Fill Valve	1/8"			
8	Gauge 0-160PSI	1/4"			

PREENGAGED OPERATION



AIR STARTER SYSTEM SCHEMATIC INSTALLATION DIAGRAMS

FIG. 2

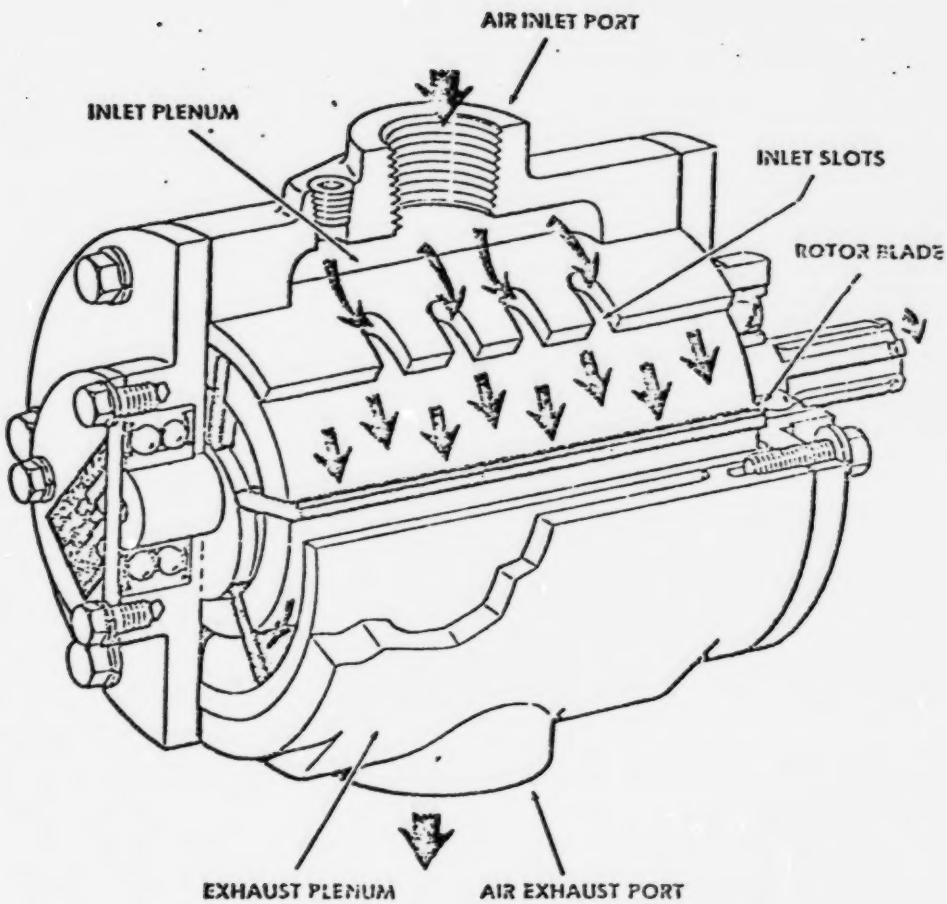


FIG. 3

OPERATION OF THE START MASTER AIR MOTOR

All suppliers of air starters produce a similar unit, and the variations are geometric and related to the vane support system.

Startmaster Air Starter

The unit which is applied to the 3306 Caterpillar Engine is shown in Fig.), the SM190 system. Its operating characteristics are: Maximum stall torque - 85 ft. lbs.

Power - 18 Horse Power at 110# air inlet pressure.

This unit can be obtained as a pre-engaged model which requires some changes in the air supply system.

Canadian Ingersoll Rand Air Starter

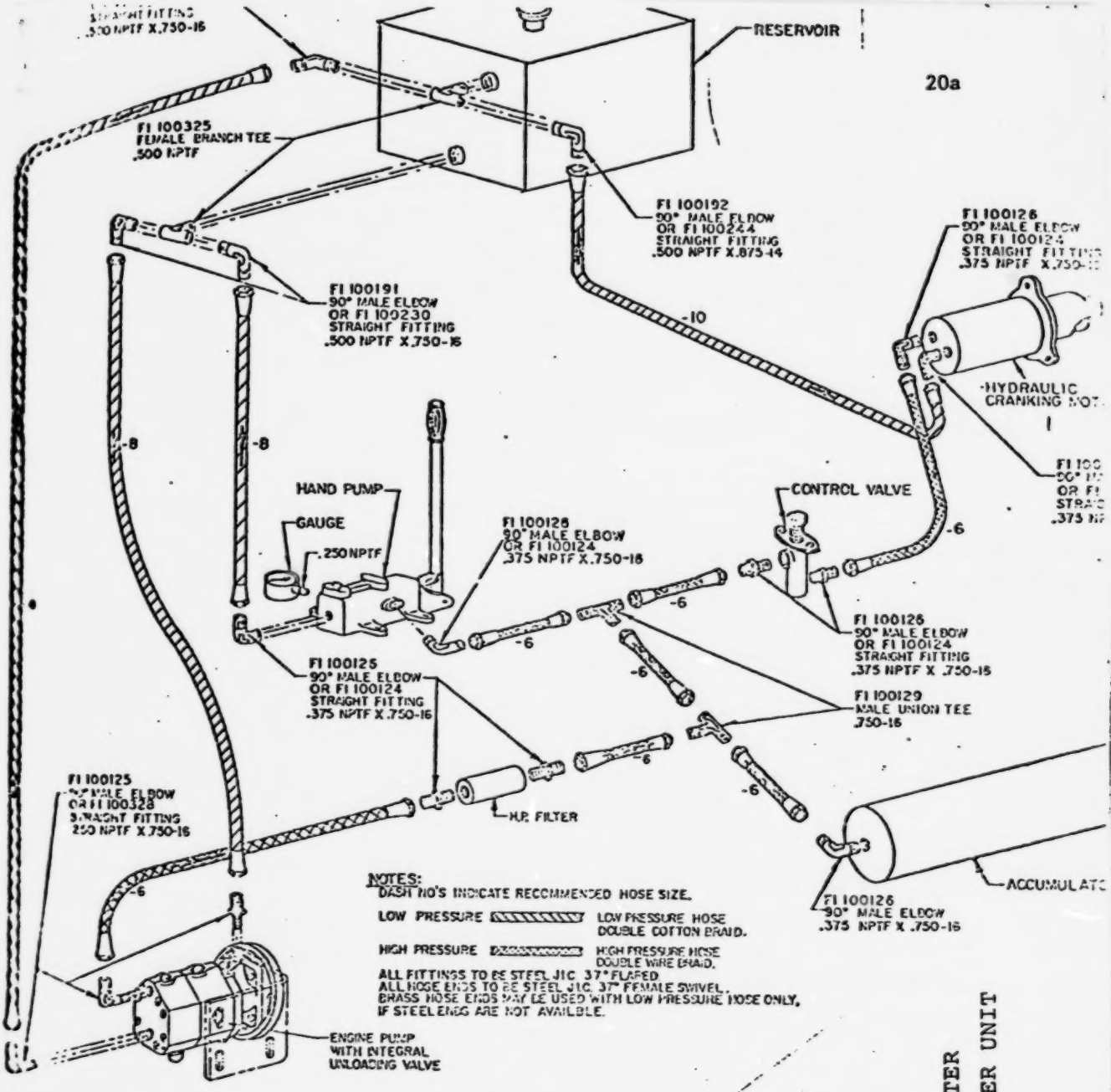
The unit selection in this case is described as their 150BMP series; with the following characteristics:

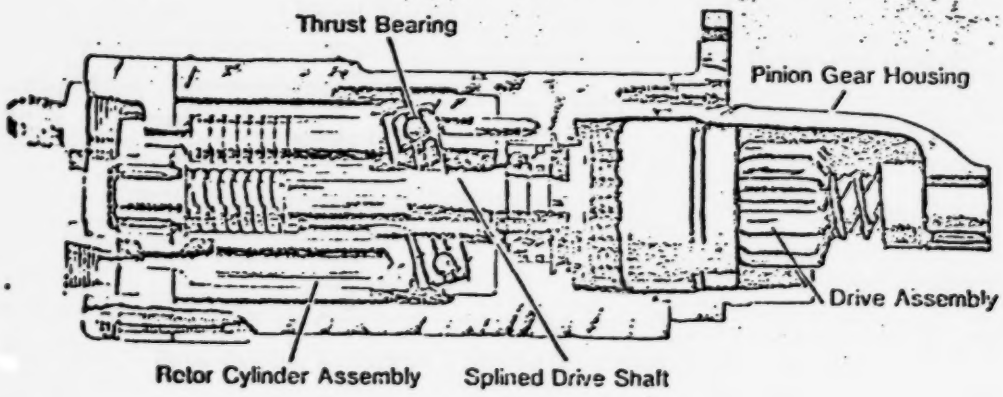
Stall torque at 90#/square " inlet pressure	81
at 150	137
Maximum Inlet Pressure HP at 90 psi	15
at 150	27

The air systems include after cooler, dryer and water traps to deal with condensation. The air recoverers are coated on the inside and the units automatically lubricated. Thus there is little likelihood of rust particles being exhausted. The exhaust air is discharged at a temperature significantly below ambient temperature.

Hydraulic Starters

A typical unit is that supplied by (Fig. 4) American Bosch Corporation. The system operates on the principle of oil under pressure turning a fluid power motor to produce mechanical energy. The oil is stored under high pressure in hydropneumatic piston accumulators and released to the hydraulic cranking motor through a starter control valve which is manually operated. The high pressure





TYPICAL HYDRAULIC STARTER
INSTALLATION AND STARTER UNIT

FIG. 4

oil enters the cranking motor through an inlet port and is directed against a series of pistons located within the cylindrical steel rotor which is splined to the drive shaft. When the pistons receive pressurized oil they move forward against an inclined thrust bearing causing rotation of the rotor. The shaft carries the Bendix drive which is engaged with the engine ring gear. The oil is returned through the outlet port to the system reservoir.

The Bosch model for the Caterpillar 3306 engine has the following performance capability:

Model CMD2A

Speed Range 0 -4500 rpm

Cranking Motor Displacement 2.02 cu in per revolution

Operating pressure 3000 psi

Locked torque (steel)

@ 2000 psi 48 ft lbs.

@ 3000 psi 72 ft lbs.

The two air starter units discussed in the foregoing represent about 90% of the units used in mining operations. The hydraulic unit is more expensive and does not have the cold weather performance exhibited by the air units.

Pinion and Ring, Gear Material

All current models of starters from the three companies listed use hardened steel pinions meshing with hardened steel ring gears. Some years ago beryllium copper pinions were available at extra cost. In a report from the Wagner Company who recently requested information on these pinions, the price quoted was beyond any realistic level and are considered unavailable. The machining of beryllium copper has become a problem due to the extremely poisonous nature of beryllium oxide.

The Jarvis Clarke Company, who makes mining vehicles although not for the coal mining industry uses fibre ring gears. For their operations they use this

as a "fail safe" system. This combination is a measure that would absolutely guarantee no possibility of impact heating hazard. They do not exhibit high service life, and are expensive to replace. The vehicle fleet at Kaiser Resources uses only hardened steel pinions and ring gears.

The starting torque values are 72, 81, 85 ft. lbs. for the three starter units examined. When this is compared to the impact energy value in the Mogan report of 177 ft. lbs. to ignite methane-air mixtures it is concluded that there is little hazard in the starter system. The units discussed are the largest and most powerful which would find use in coal mines.

For abnormal conditions such as i) trying to start a seized engine and ii) attempting to start a running engine some comment must be made. In case i) the stall torque is quite low and the pinion would lock in the ring gear and stay engaged with no vibration. The air motor would dissipate the energy of stall without problem. The case of the preengaged starter unit would not differ significantly from the nonpreengaged. It would be apparent to the operator that the engine was not turning over. The hydraulic starter would run up to stall torque, and would respond to the pressure relief valve. No problems are envisaged.

In case ii) which is a rare incident since when a diesel engine is running, it's very apparent due to the noise level. In the event this was tried, the case of the preengaged starter would cut out immediately due to the clutch action. The Bendix clutch must have gear resistance to operate or the clutch disengages. In the case of a non preengaged starter the pinion would attempt to engage the ring gear and since the ring gear is rotating a high speed it would only "butt against" the gear. The starter would over run and the noise produced should produce a reaction in the operator to disengage the starter. The pinion would likely be damaged to the extent of some loss of teeth.

Assessment of Risk Using Air and Hydraulic Starters

The risk must be considered in the light of the following conditions:

(a) Most coal mining diesel equipment is started outside the mine. There are occasions when they will be started inside, these will be limited.

(b) The range of engine size and starter replacement precludes the use of any starting device with a stall torque of over 85 ft. lbs. Provided the equivalence in torque-energy relationships is valid this represents only one-half of the energy requirement to ignite methane-air mixtures. The 177 '# represents a pure impact value which would never be experienced in a starter.

(c) The mine is ventilated adequately and there is a low probability of ventilation failure.

(d) Methanometer control at much less than unsafe levels ensures evacuation before explosion levels are reached.

Therefore it is considered that the use of air-hydraulic starting equipment does not constitute a hazard in the use of underground coal mining equipment.

Alternative Starting Systems

The basic objective to starting systems has been the impact energy characteristic of the ring gear pinion set. Most internal combustion engines use this system as do all versions of diesel powered underground coal mining equipment. In investigations a novel system was discovered, which has been used for many years in the marine engine field, and has been successfully applied to truck and bus applications. The system is called the NOVA air starting system. This arrangement allows the diesel engine to be started by injecting high pressure air directly to the engine cylinders. Air at forty atmospheres is delivered through a rotary timing valve in firing order sequence for various engine sizes and cylinder arrangements. The system concept is almost as old as the diesel engine itself but

The NOVA arrangement is a refined system reduced in bulk to fit space limitations of modern trucks and buses. This development was undertaken by Junker and Ferber in Zurich, and the "NOVA" product trade name has been accepted by their successor Ferber and Wran, also of Zurich.

The installation is a simple application and can be adapted to any diesel engine by providing one hole into each combustion chamber.

The advantages claimed are:

1. Very high cranking speed.

2. High cranking torque, less affected by low ambient temperatures.

3. No wearing parts in the starter system.

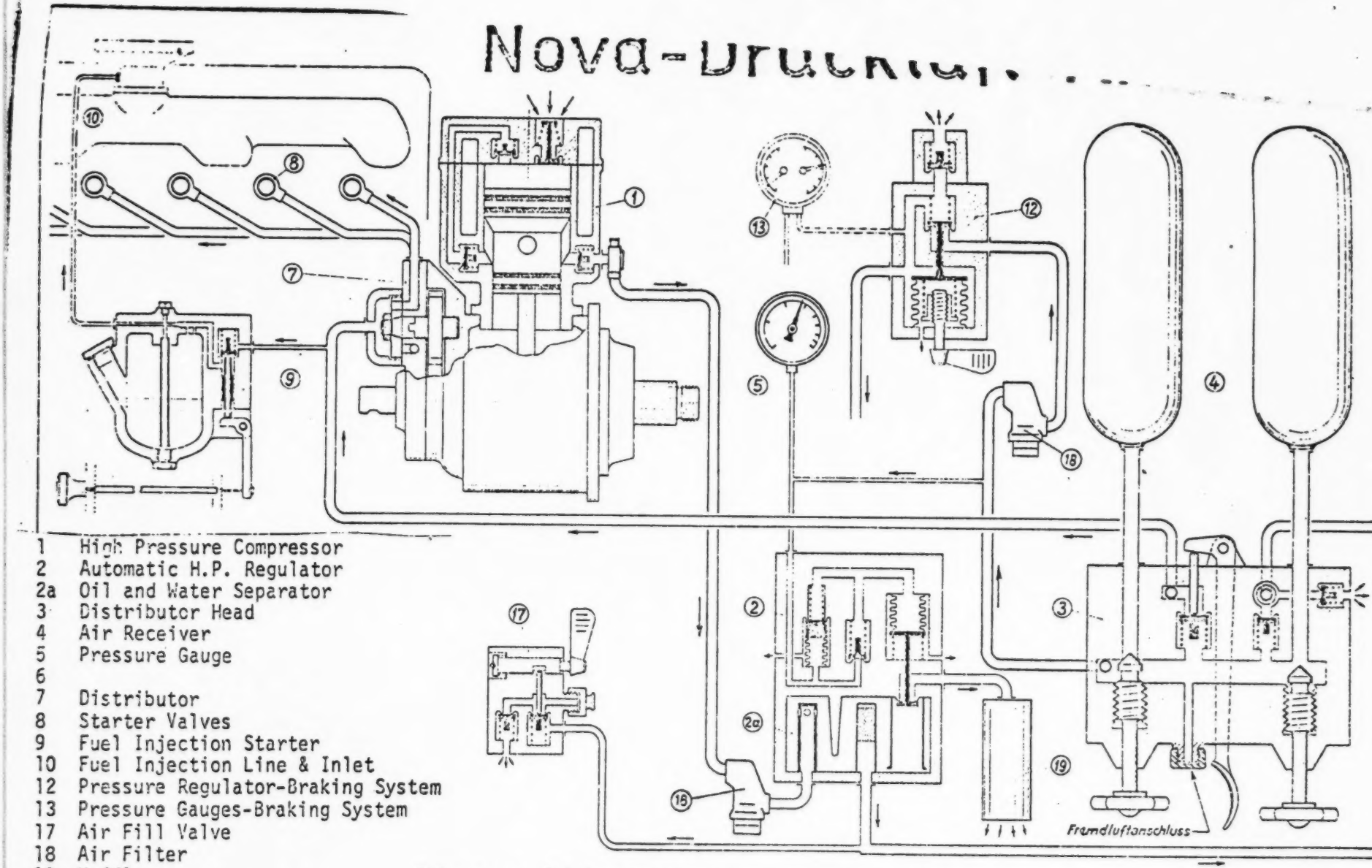
4. Continuous stop, start, capability. This allows the engine to be shut down whenever it is not doing necessary work, and instantaneously restarted when needed. Fuel savings of the order of 10%, and 25% extension of overhaul periods are claimed based on field operating data. For bus applications in Basle, Switzerland, it has been used extensively and has eliminated idle operating engine time which has led to a significant reduction in exhaust odour and emmissions, as well as noise level.

5. Elimination of fire and explosion potential in hazardous environments.

6. Reliability is excellent since the absence of wearing parts removes a number of the common causes of failure to start. The NOVA system has been applied to 30,000 diesel engines thus is a well proven method of starting.

Cost. The system is expensive at $8500-9000 for a typical application to a bus (SF = 0.72 Can. Dollars).

Installation. A schematic diagram (Fig. 5) of the standard "NOVA" installation indicates the essential parts of the system. The main difference for buses and trucks relates to the use of forty atmospheres air pressure rather than the



1 High Pressure Compressor
2 Automatic H.P. Regulator
2a Oil and Water Separator
3 Distributor Head
4 Air Receiver
5 Pressure Gauge
6
7 Distributor
8 Starter Valves
9 Fuel Injection Starter
10 Fuel Injection Line & Inlet
12 Pressure Regulator-Braking System
13 Pressure Gauges-Braking System
17 Air Fill Valve
18 Air Filter
19 Muffler

NOVA-WERKE AG 8370 EFFRETIKON

Sch-ND1×

"NOVA" AIR STARTER SYSTEM

FIGURE 5

usual eight to ten atmospheres in the compressed air system. Its application to mining equipment may be considered a departure, and surface temperature characteristics of the compressor would have to be made compatible. It offers the possibility of using pneumatics in critical areas for scoop operation where hydraulic oil leaks are a continuing hazard.

Summary

The NOVA system appears to be an excellent alternative to current starting systems on underground coal mining equipment. It is an excellent method to remove any concern about impact heating, it offers lower emission levels, better fuel economy and improved maintenance. It is felt that this approach is well worth investigation by suppliers, and government regulatory agencies.

FUNCTIONAL HEATING RELATING TO CLUTCHES AND BRAKES ON UNDERGROUND COAL MINING EQUIPMENT

Introduction

A great deal of research has been done concerning the hazards of heat producing devices on diesel powered mining equipment. Consideration should not be limited to diesel powered vehicles but all vehicles using brakes. In the course of searching for background material a number of research establishments were visited, a good sampling of brake manufacturers were contacted, and a mining operation using diesel powered equipment almost exclusively, was inspected.

The general reaction of all was that the 300°F surface temperature requirement (UK and Canada) as specified for diesel engines would likely be a safe requirement for braking surfaces. There did not appear to be much concern about vehicles equipped with standard shoe or disc brakes but there was some concern about the locomotive brakes on monorails and tracks. When brake blocks are employed, the use of metallic brake lining is almost standard and great concern is raised from time to time regarding materials used. It is generally agreed that the light metals, particularly aluminium and magnesium should not be used. Thus cast iron on steel tends to be the usual material used. Under extreme braking conditions sparks are generated, and this has been cause for alarm and much investigation. The research work has been mostly addressed to spark ignition by soft light metallic particles. Very elaborate means of producing sparks, and quite novel explosion mixtures have tended to characterize the research work. Conditions in the controlled experiments do not bear very significant relationship to the underground mine. It would be naive to suggest that such work is not of continuing interest since understanding the fundamentals of explosion reactions is essential to the development of better methods of dealing with safety problems.

Sparks are a common scene on tracked locomotives in the mine or out of it. Suzuki et al. (13) performed a series of experiments using a friction wheel and slider simulating the locomotive wheel and track and concluded that an explosion may be induced in coal dust dispenser in air provided the temperature of the ignition source is higher than the minimum ignition temperature of the coal dust. Surface temperatures of 1000 C-1000 C will not induce ignition by friction even with large heating surfaces. The ignition temperatures of the coal dust was in the order of 600-660°C. H. Titman (5) has indicated ignition of methane air is virtually impossible with sparks from rail-wheel friction. However is a series of sparks were caught on a collector on the rail, ignition could result.

Confirming research has been done which indicates a low, if not non-existent hazard in ignition of methane-air with any braking device, when surface temperatures are below 1000 C. There is some hazard when explosive mixtures of methane-air and coal dust dispersions occur, in a braking environment. In underground environments it is unlikely if not impossible to achieve brake component temperatures over 300°F due to operating characteristics. The clutch system which is a rarity for diesel vehicles in coal mines is only a friction device when shifting gears. Unless deliberately "slipped" for an extensive period no risk attaches to its operation.

Friction Heating in Diesel Powered Coal Mining Equipment

It is evident that all vehicles used in a coal mine must have stopping capability. The braking systems used vary with the vehicle type. Locomotives on tracks, and on monorail systems usually employ wheel and track brakes. In the case of the rail locomotive brakes the vehicle is stopped by block brakes on the wheels or by pushing a brake block down on the rail. The monorail is stopped by applying a clamping action on the rail, with suitable brake blocks. Rubber

(1) Grades not exceeding 20%.

(2) Vehicle speed seldom over 5 mph.

(3) Wheel brakes seldom used due to down-gearing inherent to vehicle.

(4) Wet or muddy roadways are quite usual.

(5) Extremely adequate ventilation.

Each of these parameters tend to limit heat input to brakes, and the temperature decay curve from maximum temperature attained is an extremely steep one. Examples taken from the Skelley & Loy report (14) indicate a typical analysis of energy considerations and brake heating.

Example. A 50,000 lb. shuttle vehicle is stopped from an initial velocity of 6 miles per hour (8.8 ft/sec) on a 20% downslope and accelerates at .27 G (8.7 ft/sec) stopping time is then

$$t = 8.8 \text{ ft/sec} / (.27 \times 37.2 \text{ ft/sec}^2) = \underline{1.15 \text{ seconds}}$$

$$\text{Stopping distance} = \frac{8.8 \text{ ft/sec}}{2} \times 1.1 \text{ sec} = \underline{4.6 \text{ feet}}$$

Total Energy dissipated in the stop is the sum of

the Potential Energy $E_P = WSG$

the Kinetic Energy $E_K = \frac{WV^2}{2g}$

The Rotational Energy $E_R = 0.15\ E_K$ (developed value)

W = veh. weight
S = stopping distance
G = % grade

V = vehicle velocity
g = gravitational constant

In this case

$$\text{Total Energy } E_T = 1.15\ (\tfrac{1}{2} \times \frac{50000}{32.2}) \times (8.8)^2 + 50000 \times 4.6 \times \sin.\ 11^{\circ}18'$$

$$= 69.100 + 45000 = \underline{114.000 \text{ ft/lbs.}}$$

or <u>147 BTU's</u>

- if the stopping deceleration were reduced to .07G.

t = 8.8 ft/sec (.07 x 32.2 ft./sec.) = 3.9 seconds

s will be then = $\frac{8.8}{2}$ x 3.9 = 17.2 ft.

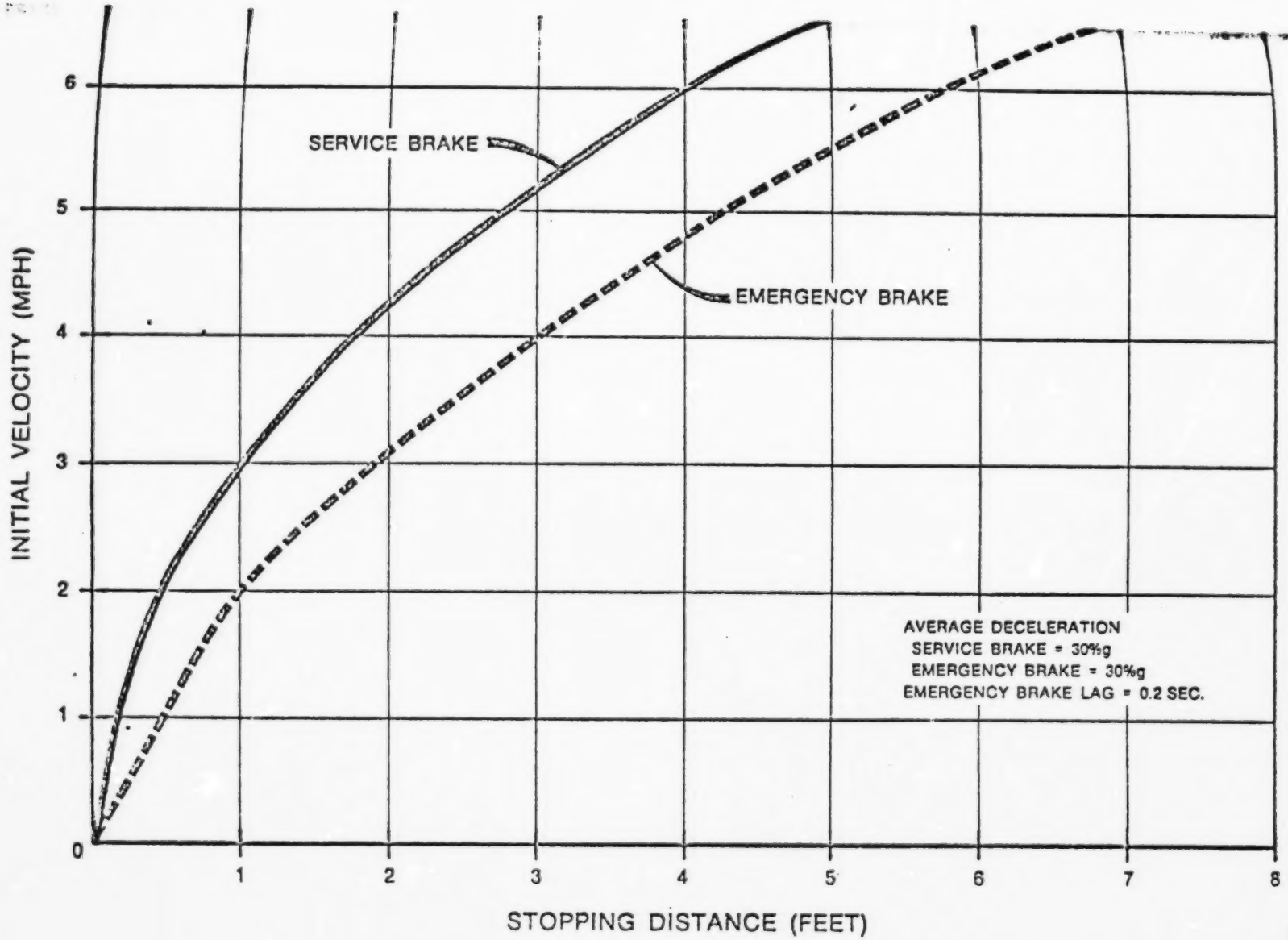
$$E_T = 69.100 + 168.000 \quad 237.000 \text{ ft/lbs.}$$

or 305 BTU's

These heat inputs can be equated to the maximum temperature of the absorber in this case the disc by estimating the heat capacity of the discs, with two 12" disc brakes x ½ thick. The discs would weigh about 16#, the specific heat for steel/iron is .12 BTU/lb/^{o}F then each disc has a thermal capacity equal to 1.9 BTU/^{o}F.

In the first case this would lead to a maximum increase of temperature of 39^{o}F each disc and in the second case 80^{o}F each disc. The Skelley and Loy report (14) indicated most vehicles tested fall in the range predicted. There were seldom any heat levels above 100^{o}F. It is likely that there are hot spots over this level but the temperature is dissipated very quickly through windage and transfer to surrounding components.

It can be agreed that long runs down steep slopes can lead to higher temperature levels. In the tests reported by Shelley and Loy no overheating was observed. It is unlikely an experienced operator would "ride brakes" when he is familiar with the "engine gear braking" capability of the vehicle. If the brakes are chosen properly, that is to say provide at least .34 Gross Vehicle Weight braking force or the stopping distance for a service brake with this brake force capability would equal a stopping distance of approximately 4 ft at 6 mph on level ground. (Fig. 6)



30a

RECOMMENDED STOPPING CAPABILITIES
ON A LEVEL ROAD SURFACE

FIGURE 6

Manufacturers' Reactions

Brake manufacturers and vehicle suppliers did not display concern about the temperature hazard in brakes as it relates to explosions of methane-coal dust mixtures. The main parts of the braking system are geometrically shaped to inhibit heavy coatings of coal dust. Windage and washing in the watery environment assist to keep critical layers of dust to a minimum.

In observing the terrain traversed in the Sparwood mine, it is inconceivable to suggest an 11 mm layer of coal dust could build up on any of the braking surface parts subject to high heat inputs. The drums and discs are the critical areas. Both rotate continuously and there are no surfaces where coal dust can easily accummulate. Typical brake test data from manufacturers relating to 18 in disc brakes at normal operating loads show: disc temperature 290°F and lining outboard and inboard and, 160-180°F in the boot seal, and brake fluid. The EMR Report by Mogan (3) cites the threshold level for ignition of methane-air by frictional rubbing requires at least .5 kw/cm^2 (4 HP/in^2) or a surface temperature of 975°F for metal and 1250°C for non-metal parts. Clearly no braking system is likely to attain these temperatures and still retain fluid or seals. An estimate of the energy input to the case of the 18 in. disc brake at 3000°F disc temperature can be made by inference. At 4 HP/in^2 and a brake pad area of about 28 in^2 the energy observation would be 4 x 4 x 50 ft lbs/sec = 61,600 ft lbs sec or 3,696,000 ft lbs/min.

Data from experimental graph (Fig. 7) indicates that this energy level is far beyond those that can be attained by this brake.

TYPICAL TEMPERATURE ENERGY RELATIONSHIPS

DRY DISC BRAKES 18-20" DIAMETER

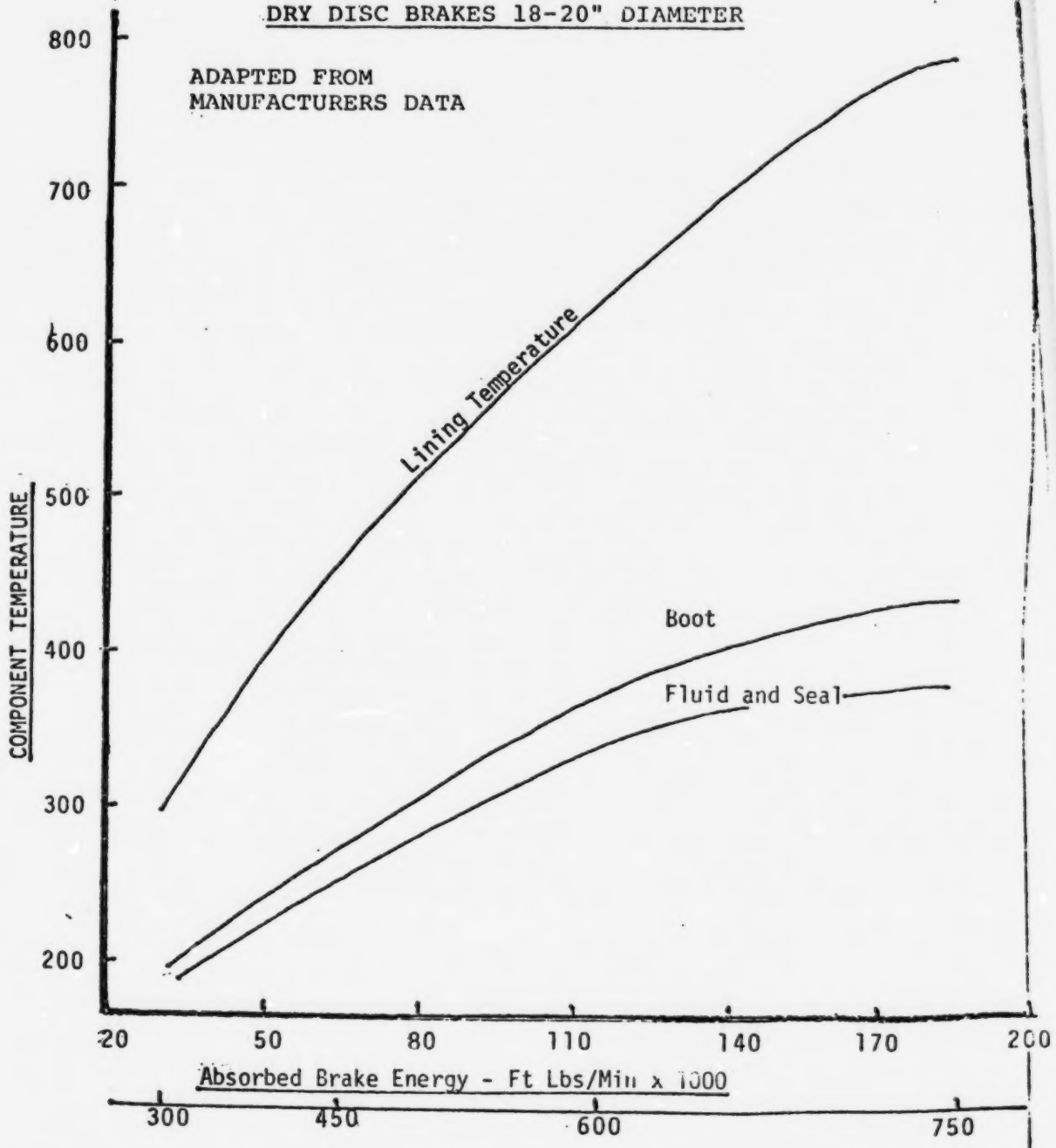


FIG. 7

If the HP per in^2 criteria is applied to the same experimental graph we should get a reasonable estimate of the peak temperature at the energy absorption level calculated. The lining area for this brake or one of its class (Goodrich Disc No. 419-151-1 & 2) is 45.5 sq in. At 140,000 ft lbs/min = 4.24 HP and for 45.5 in^2 of lining represents a level of $\frac{4.25}{45.5}$ = 0.09 HP/in^2. This level could be sustained although the disc temperatures would be 650°F. We can also determine that 0.09 HP/in^2 is by far less than the critical HP/in^2 criteria.

(i) If this energy level could be maintained the temperature reached would be too high. However, this is unrealistic dealing with disc brakes.

(ii) There is no likelihood of coal dust being retained on the rotating disc or the vertical lining blocks. The temperature level on the externals such as boot and seal will not exceed 300-350°F which is quite close to the criteria for coal dust layers stated as 300°F - 428°F.

(iii) It is unlikely that accummulations of coal dust would ever approach the levels indicated as hazardous.

(iv) The braking levels in this example are far above any normally encountered in operating diesel powered mining equipment.

The Skelly and Loy report commissioned by the U.S. Deparment of the Interior gives details of tests run in coal mines using traditional measurements ....

of stopping distances, vehicle velocity, grade, and disc temperature. The following will summarize their findings in a general way.

The goals were to evaluate the braking performance of all rubber tired coal mining equipment vehicles, and make recommendations for the equipment studied. There were 89 machines tested and 350 tests performed in 9 underground coal mines. The test of adequacy in their tests was a brake force to vehicle weight ratio of .34 or greater on slopes up to 20%. This is equal to deductions of .3g on the level and .1g on a 20% road grade.

Direct temperature measurements indicative that no readings were noted over 300°F through stopping tests. It is also significant that the vast majority of the test work was done on electrically driven vehicles. Service brake performance standards were recommended in the report as follows:

> All source brakes operating on less than 20% grade should be designed to have a minimum braking force to gross vehicle weight ratio equal or in excess of .34. This is said to be equivalent to that force required to produce an average deceleration of .3g (9.7 ft/sec^2) on a level surface with the vehicle loaded. Graph (Fig. 7) indicates the relationship as related to stopping distance and initial velocity. Time base data in the Appendix III cites the experimental results.

In the subsequent pages there will be some discussion related to wet disc brakes. Calculation data from one of the leading manufacturers is included in the appendix. The design criteria for HP/in^2 of lining is limited to 1.75 HP/in^2. The usual designs for a .4g distribution 17% grade 10 mph initial velocity show a 1.48 HP/in^2 peak with a .75 HP/in^2 average. This reinforces the earlier statement regarding the unlikelihood of a braking system being required to cope with a friction load of 4 HP/in^2.

Scharf Monorail System

Through the courtesy of Mr. P. Mogan of the Canadian Explosive Laboratory, the calculations for brake heat dissipation has been developed as follows for the Scharf monorail system.

Braking tests of the Scharf Monorail determined that the emergency brakes stopped the 12,800 kg (28,266 lb), GVW unit in 123 cm (4.03 ft) from a speed of 3.3 metres/sec (10.8 ft/sec) on a level track, and in 173 cm (5.7 ft) from a speed of 3.4 metres/sec (11.2 ft/sec) on a 7½% incline.

Level track case:

$$u^2 = 2\,a\,S$$

$$a = \frac{10.8^2}{2 \times 4.03} = 14.5 \text{ ft/sec}^2$$

$$u = at$$

$$t = \frac{10.8}{14.7} = 0.75 \text{ sec}$$

$$w = 28{,}266 \text{ lb.}$$

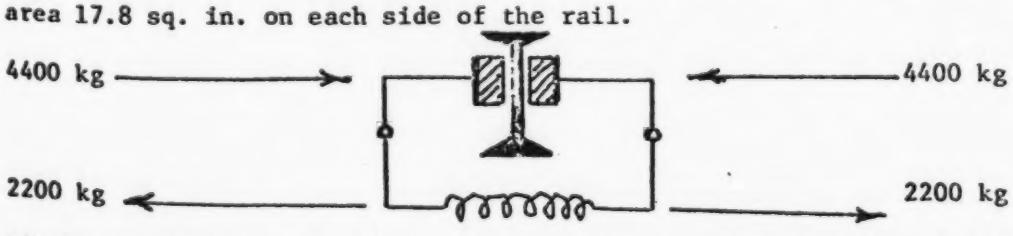
$$F = \frac{W}{g}\,a = \frac{28266}{32.2} \times 14.5 = 12{,}728 \text{ lbs.}$$

$$V \text{ average} = \frac{10.8}{2} = 5.4 \text{ ft/sec}$$

$$FV = 5.4 \times 12{,}728 = 68{,}731 \text{ ft lb/sec}$$

$$= \frac{68{,}735}{550} = 124.9 \text{ HP}$$

The brakes are applied by a double acting spring which exerts 220 kg (4850 lbs) across a 2 to 1 lever arm to a set of three sintered bronze brake pads of total area 17.8 sq. in. on each side of the rail.



If the co-efficient of sliding friction is assumed to be about 0.6 for sintered bronze on mild steel, the component of brake force parallel to the rail for

each set of pads:

$F = 4400 \times 2.205 \times 0.6 = 5820$ lbs.

Total brake force = $2 \times 5820 - 11640$ lbs.

$FV = 11640 \times 5.4 = 62{,}856$ ft lbs sec

$\therefore$ HP dissipated by brake = $\frac{62{,}856}{550} = 96.1$

(this indicates that some of the retarding force was derived from the hydrostatic drive)

$\therefore$ Power dissipation in brake = $\frac{96.1}{17.8 \times 2} = 2.7$ HP/in^2

or, if drive retardation assumed negligible

$$= \frac{124.9}{17.8 \times 2} = 3.5 \text{ HP/in}^2$$

Inclined Track Case:

$u^2 = 2a\,S$

$a = \frac{11.2^2}{2 \times 5.7} = 11.0$ ft/sec^2

$u = a\,t$

$t = \frac{11.2}{11.0} = 1.02$ sec

$F = \frac{28{,}266}{32.2} \times 11.0 = 9656$ lbs.

V average = $\frac{11.2}{2} = 5.6$ ft/sec

$FV = 9656 \times 5.6 = 54090$ ft lbs/sec

$H = 5.7 \times \sin 7\frac{1}{2}^{\circ} = 5.7 \times 0.130 = 0.74$ ft.

$PE = 0.74 \times 28{,}266 = 20945$ ft lb

PE power dissipated = $\frac{20945}{1.02} = 20534$ ft lb/sec

Total maximum power dissipated = $\frac{54090 + 20534}{550} = 135.6$ HP

Power dissipation in brake (drive retardation assumed negligible)

$$= \frac{135.6}{17.8 \times 2} = 3.8 \text{ HP/in}^2$$

which would reduce the heat load.

The monorail is particularly sensitive to methane accumulations being from the roof when lighter gas would tend to accumulate and flow. Accumulations of coal dust are more likely on stationary hanging rails as well. With sintured bronze brake pads there should be no sparking problems related to stopping this type of locomotive.

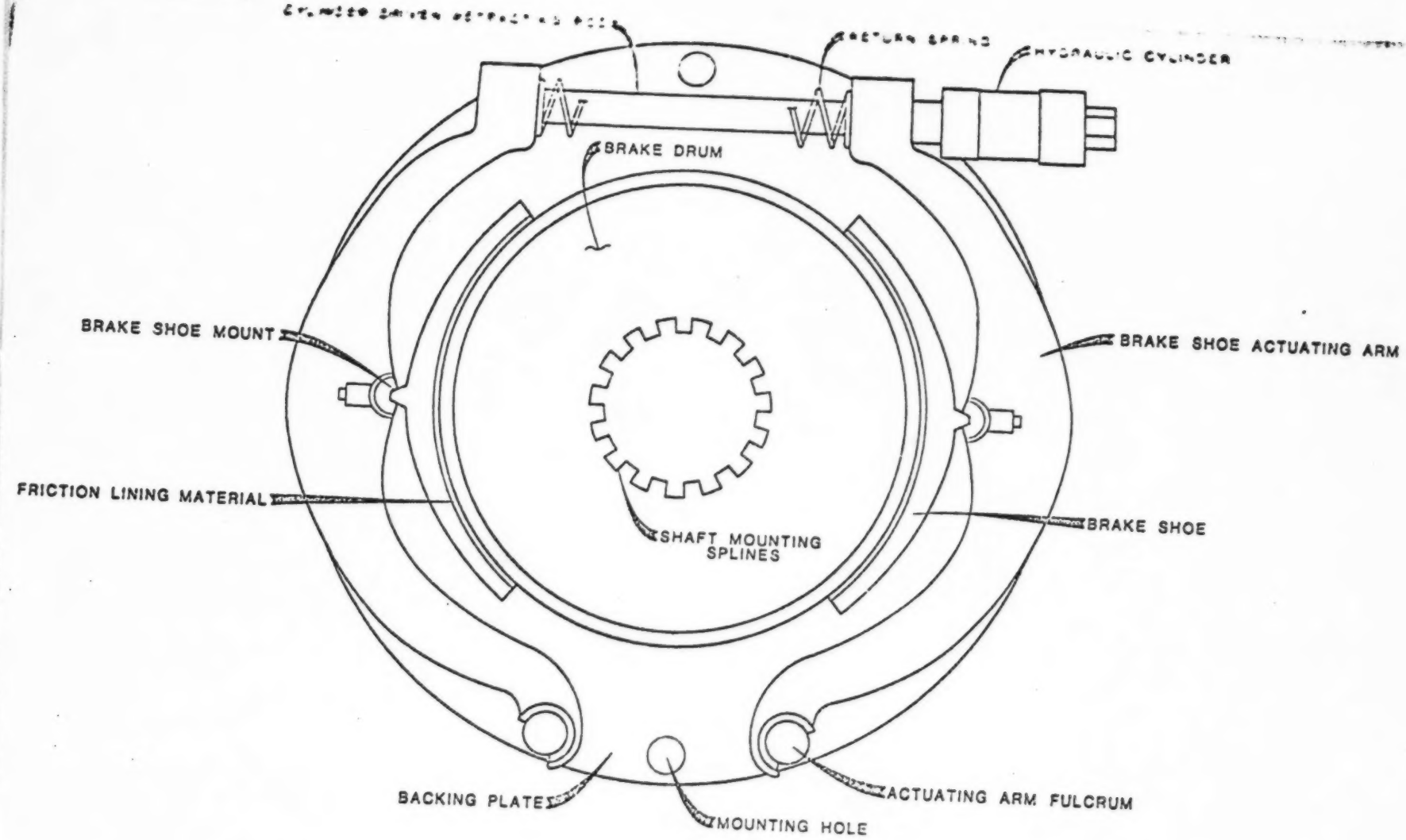
Typical brake configurations are illustrated in the following (Figures 8, 9, 10, 11, 12) sketches, and details of a few brake manufacturers products relating to diesel powered equipment will be found in the Appendix III.

Summary

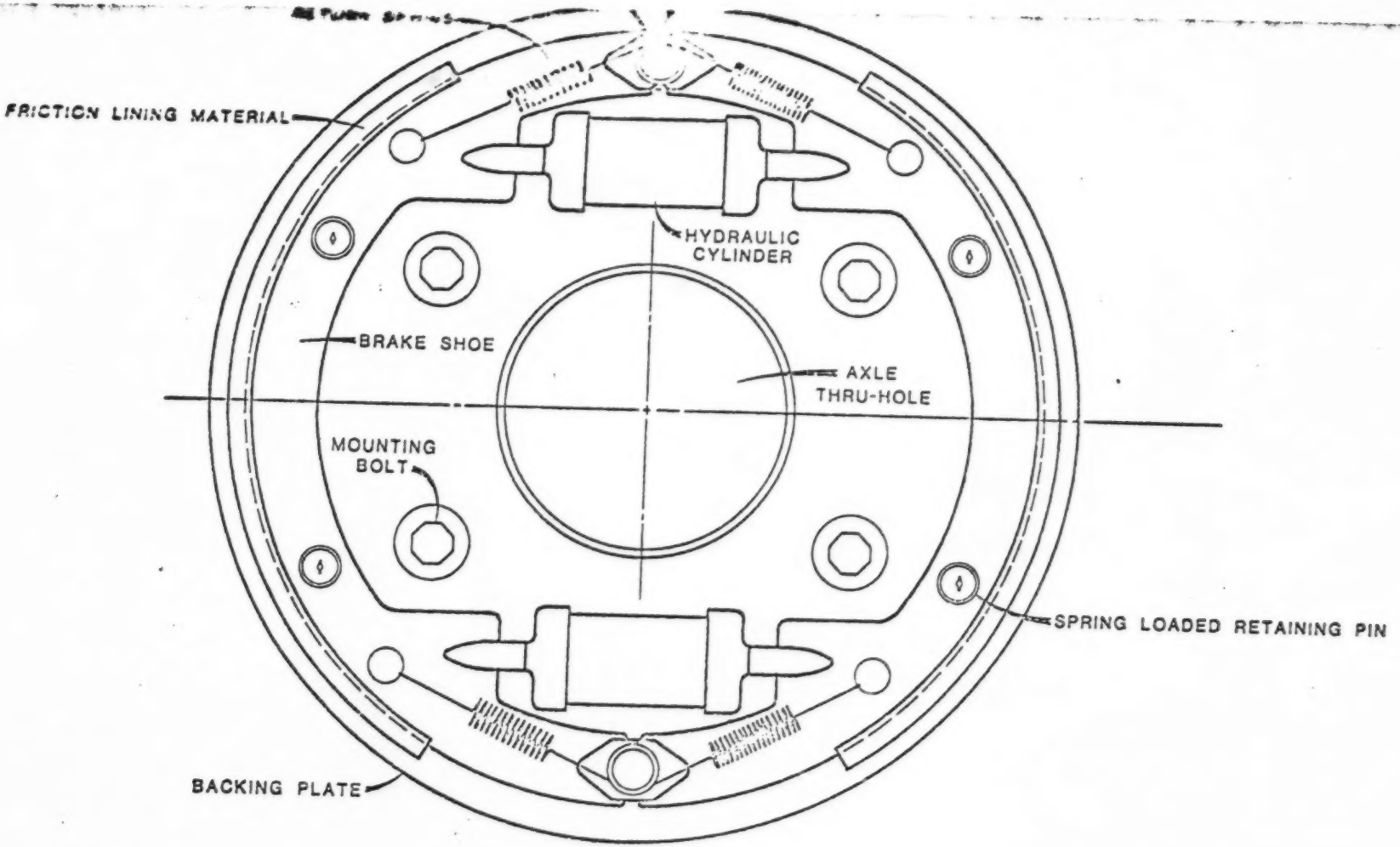
There is little risk in using braking systems on diesel powered equipment, found in coal mines as they are currently designed. Frictional energy release will seldom if ever raise drums or discs to over 300°F. On dragging brakes under extreme conditions temperatures in the range of 500°F - 700°F are conceivable. Even at this temperature which is restricted to the drum, or disc and lining surfaces there is no possibility of coal dust deposition in thicknesses which could be considered hazardous. In this unlikely event the other parts of the brake would not likely gather enough coal dust at their likely lower temperature of 300-350°F.

Alternative Braking System for Diesel Vehicles in Underground Coal Mines - Wet Disc Brakes

From successful work by Caterpillar some years ago, and the broad based technology of the automatic transmission, multi-disc fluid filled brakes have recently come on the market. They will find good application on all types of off "highway" vehicles.

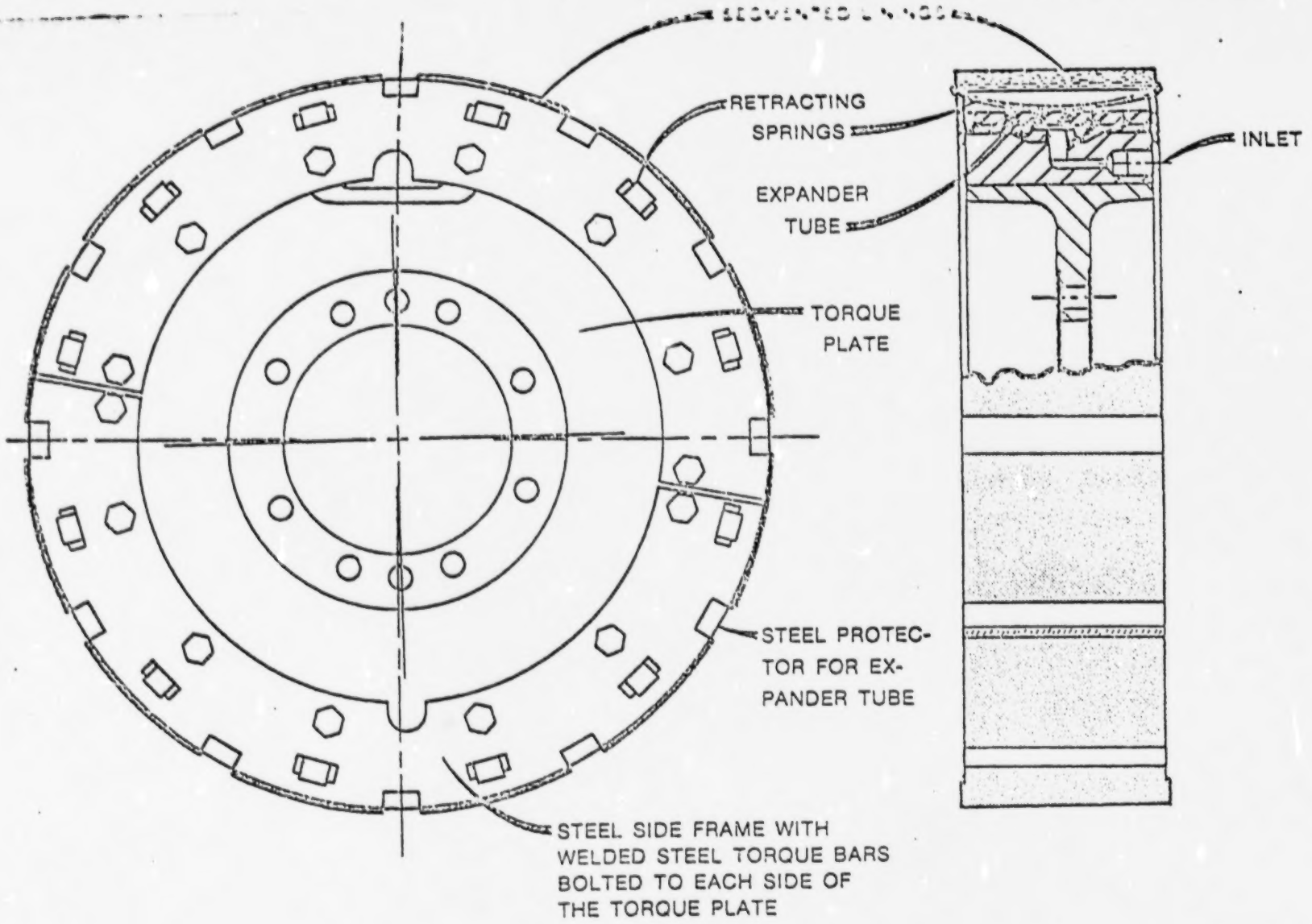


TYPICAL BAND - TYPE BRAKE
EXTERNAL CONTRACTING SHOE
FIGURE 8



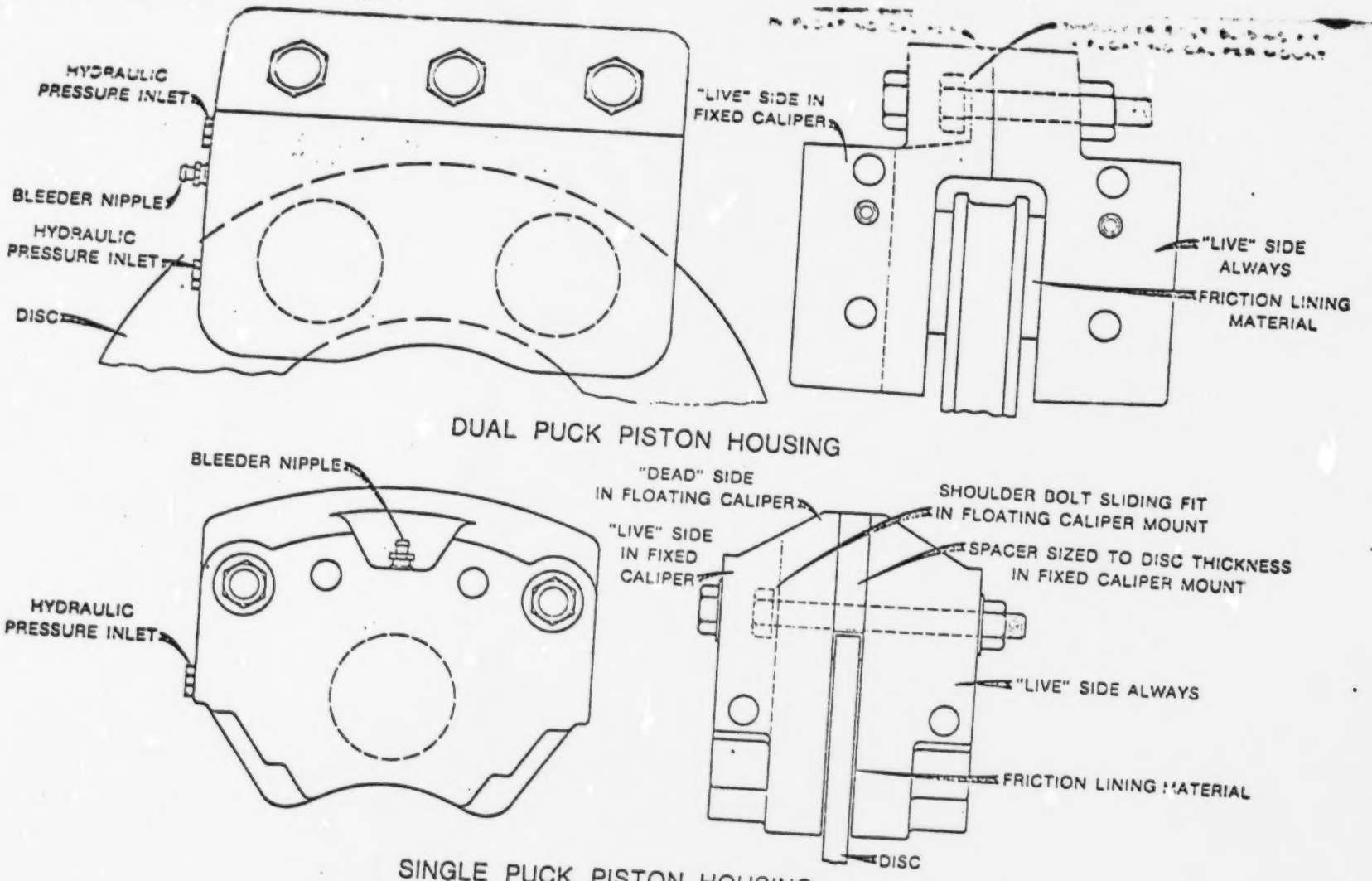
TYPICAL SHOE BRAKE INTERNAL EXPANDING SHOE

FIGURE 9


RETRACTING SPRINGS
EXPANDER TUBE
INLET
TORQUE PLATE
STEEL PROTECTOR FOR EXPANDER TUBE
STEEL SIDE FRAME WITH WELDED STEEL TORQUE BARS BOLTED TO EACH SIDE OF THE TORQUE PLATE

EXPANDER TUBE TYPE HYDRAULIC BRAKE

FIGURE 10



CALIPER DISC BRAKES

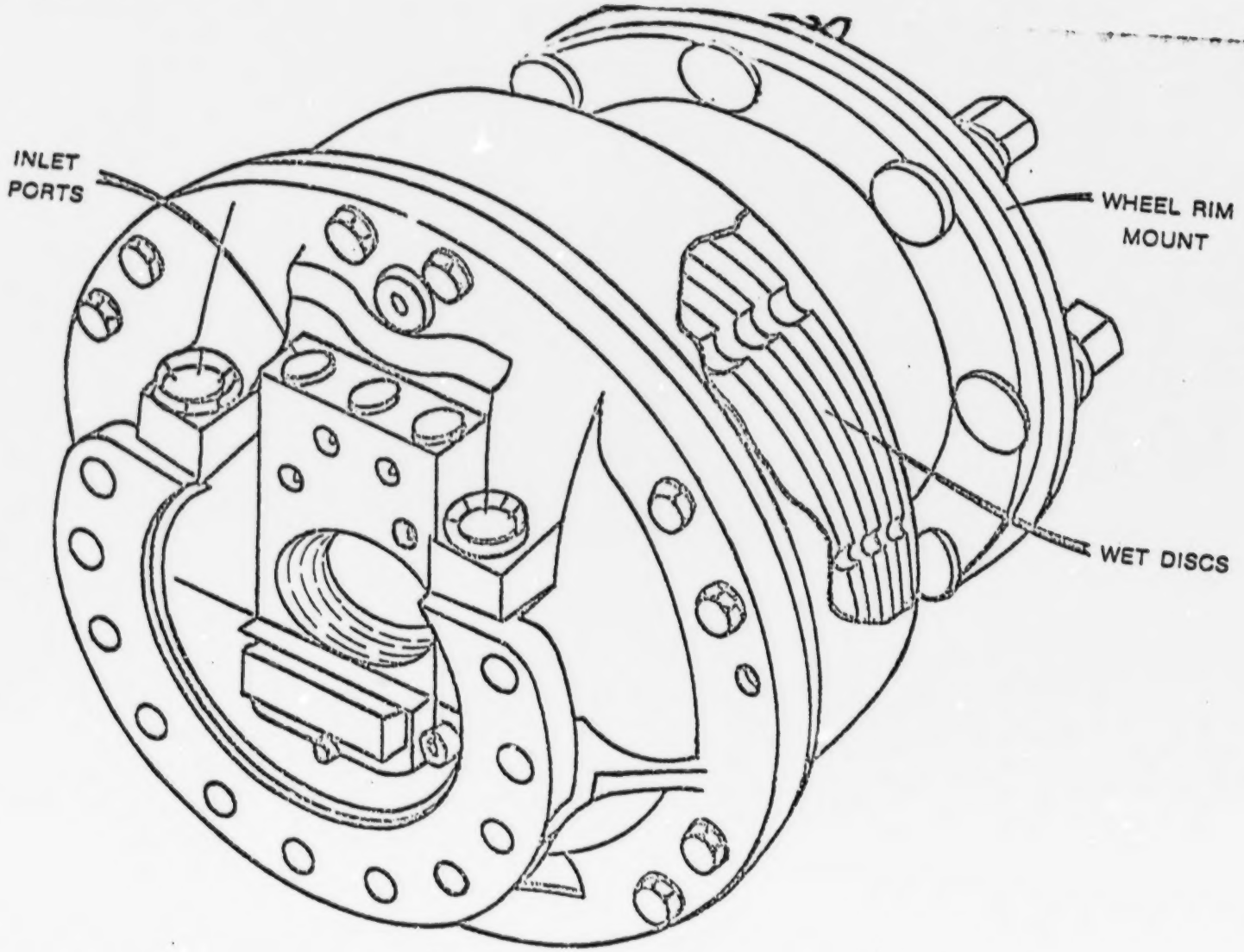
FIGURE 11

The Rockwell International Corporation and Clark Equipment have this kind of brake available as original equipment, and the latter has designs for retrofit. The main advantage claimed is the "maintenance free" characteristic of the lining component. The units absorb energy by fluid shear, thus linings are not worn perceptibly over very long periods of operation.

This development has a natural application to underground mines as it is without any friction energy problems. The system operates at 250°F controlled temperature so qualifies very well for tolerated temperature level. The only drawback seen at the moment is the expected necessity to use fire resistant hydraulic fluids, whose characteristics do not appear compatible with the proper operation of a wet disc brake. In a closed system it is unlikely to be a problem since most hydraulic oil fires have been related to severed hoses. Research is underway to determine if there is a suitable fire resistant fluid. A trade off regarding hazard due to friction heating or hydraulic oil hazard is indicated here. There is a very heavy consideration on the service requirements to the user. The maintenance on brakes would be substantially reduced at the mines which should be considered as another parameter in selection.

Marketing people are quite convinced that wet disc brakes will be standard equipment for off the road vehicles, within the next few years. A design guide for wet disc brakes used by one of the larger manufacturers is included in the Appendix III.. A typical brake is sketched in Figure (12). A product description is as follows:

- Demountable wet disc brake design may be externally or sump cooled, to be adaptable to most axle assemblies of recent make.
- Direct wheel braking
- No effect on wheel-track variation
- 2-8 discs depending on requirements



INTERNALLY SEALED WET MULTI-DISC BRAKE

FIGURE 12

- Torque range .6g hydraulically applied

  .2g mechanically applied spring brake

- Medium duty cycle - sump cooling for loaders

- Severe duty cycle - external cooling for trucks and loaders

- No significant impact on axle manufacturing

- Friction material - graphitic bronze or paper discs according to application

- Hydraulic fluid GL-5 hypoid gear oil for sump cooling or Dextron or SAE 30 mineral oil for external cooling

- Life expectancy - five year medium duty cycle and heavy duty cycle

- Actuation means - hydraulic apply with spring fail safe application

- Cost competitive with current drum brakes.

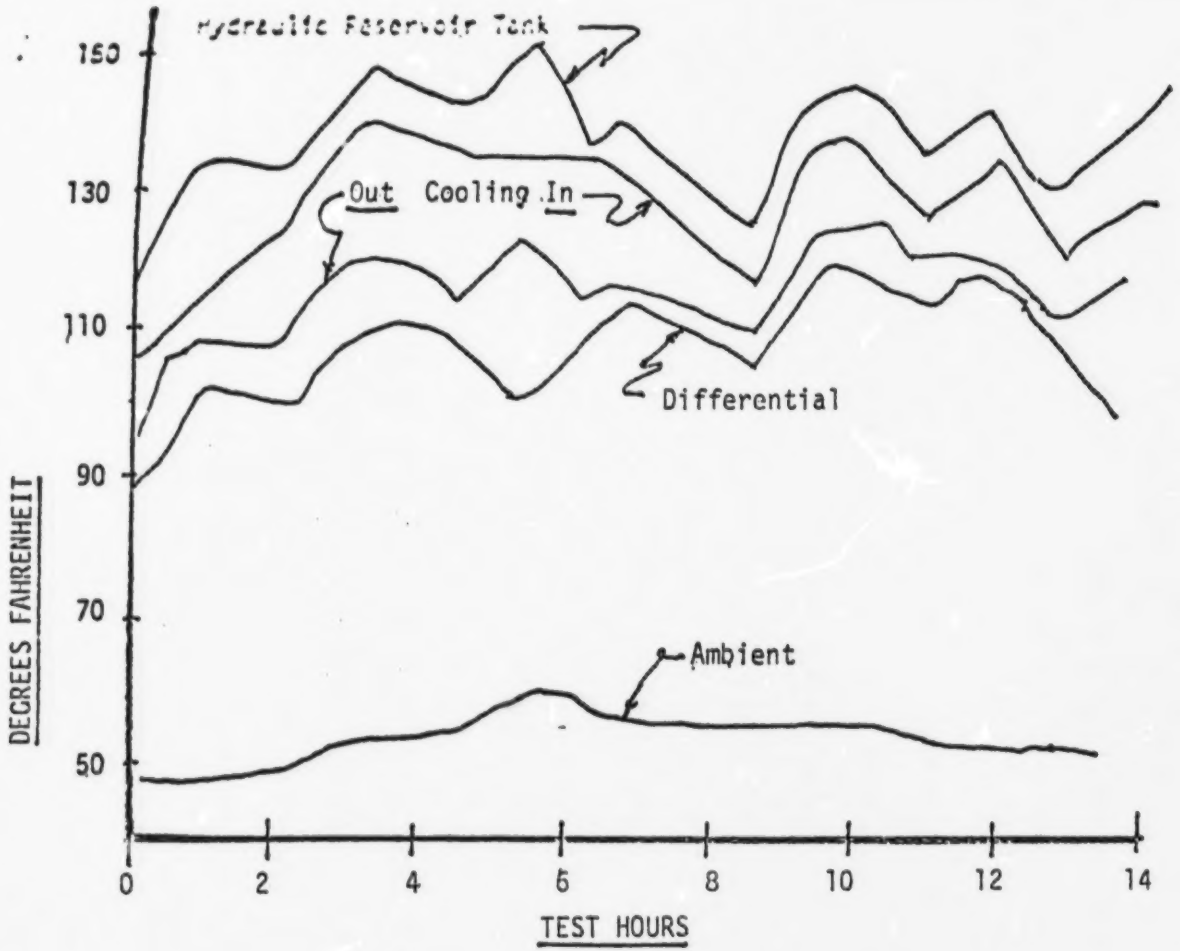
Summary

If it is essential that surface temperatures on braking systems are completely controlled, the wet disc brake offers this possibility. They are designed to operate at a peak oil temperature of 250°F, which falls well within the ranges usually specified for surface temperature. Fig. 13 is a plot of a tank temperature profile on a test circuit on a twelve hour test.

Frictional Heating by Clutch Mechanisms on Diesel Powered Coal Mining Equipment

The investigation has not found clutches in general use in underground mining equipment. The only vehicle turned up using a clutch was a Jeep type four wheel drive vehicle with a flameproof diesel installed.

It is apparent that the only time the friction characteristic of the clutch disc is brought into action is when gears are shifted. During this time the disc is used to absorb the shock of the coupling of the engine to the transmission. On start-up some "slip" is usual for torque pick-up. In normal operation there is little heat build up.



TEST CYCLE

Time Full Cycle $2\frac{1}{2}$ Min.

Stops
High Speed 2

Normal Speed 3

Smooth Track

Graph adapted from Manufacturer's data.

TYPICAL TEMPERATURE PROFILES FOR WET DISC BRAKES ON CYCLE TESTS, INSTALLED ON LARGE LHD VEHICLE

FIG. 13

Abnormal Clutch Operation

Abnormal clutch operation would be considered that in which the clutch was deliberately slipped for long periods of time. This could occur due to an inexperienced driver, or one who 'rides' the clutch, or alternately, in a 'rocking' mode to free a stuck vehicle.

One can construct an analogue to the disc brake, except the clutch disc has the lining installed. If it is assumed that the clutch is a 12 in. outside diameter unit, with a 2 in. wide facing, the friction faces would be π x 11 in. x 2 x 2 faces = 138 in^2. The engine is unlikely to be over 100 HP in coal mining applications. Under slipping conditions, 100 HP would be much more than ever obtained. Assuming 100 HP could be fed into the clutch continuously in 100 x 550 = 55,000 ft lbs/sec or 3,300,000 ft lbs/min was required to be absorbed. If the disc brake test data (Fig. 7) can be used as a guide this would likely raise the pressure plate and fly wheel temperature to abnormal levels which would cause the clutch surface to break down. Since it is in a contained area, the windage factor would not dissipate as much heat, so the temperature may be higher. However, the temperature anywhere on the clutch housing would not rise very quickly. The ultimate failure would occur in the clutch disc lining since it is designed for shock load and does not have as high a temperature resistance characteristic as brake lining.

It is extremely unlikely that the clutch disc on breakdown would produce heated pieces which would ignite coal dust or methane. There is little likelihood of coal dust build-up in the clutch area if it is sealed reasonably.

Testing at Sparwood, B.C. on Frictional Heating - Feb. 13-23, 1979

The Skelley and Loy Report (14) included a good deal of data from mine site testing. The investigation made in the course of this contract did not allow for a well planned field test program. There is also the problem of operation interruption which is of major interest to the operator. In order to attempt to determine disc temperatures in actual operations a simple experiment was undertaken at Sparwood B.C. All vehicles used except those with hydrostatic drive were equipped with hydraulically operated disc brakes. At the start of one shift the outer edges of the discs were painted with "TEMPLILAQ" which is a temperature sensitive paint. The colours used were equivalent to melting temperatures of 250-300 and 350^{o}F. The vehicles were then moved to their normal duties in the development area of the operations.

Several attempts were made to assess temperature in the brake discs without success. The vehicles tested were the pipe trucks EIMCO model 911. In all cases the paint was rubbed off. The mine management was reluctant to approve the use of thermocouples or any recordary instruments using batteries. The test scheme was abandoned after two weeks' trial. The mine personnel were most co-operative and interested in the program.

CONCLUSIONS AND RECOMMENDATIONS

Impact energy in diesel engine starting equipment does not constitute a hazard in methane-air mixtures. The input torque to starter systems investigated is much less than the energy threshold for ignition of methane-air mixtures reported in current and past research. This is true for all starter systems in approved vehicles used in Canadian coal mines, for both normal and abnormal operations of the starter.

Frictional heating in braking systems on diesel equipped, rubber tired transport, load haul and dump, and other vehicles, the energy levels and surface temperatures will not reach dangerous levels in normal or abnormal operation, where ignition of methane-air mixtures, or oily coal dust layers are of concern.

This conclusion is based on the critical values as determined by research for temperatures, energy levels, and layer thickness of coal dust. It is concluded that under mining conditions, critical temperature and energy levels are not exceeded, and coal dust layer build up on braking system surfaces will not reach the depth to be hazardous.

Currently available literature and long operating experience determines that sparks associated with locomotive braking are not hazardous. This view is shared by the writer, with somewhat less confidence.

The ventilation and methane monitoring systems in an underground coal mine further mitigate concern about the operation of starters and brakes.

RECOMMENDATIONS

The existing Canadian regulations covering starting and braking systems in M12 appear to be adequate. A performance standard should be added to ensure a common level of braking capability in all approved vehicles.

There are gaps in the area of research. It would be appropriate to extend some effort, to reinforce the opinions regarding open sparks from cast iron-steel braking surfaces. Some extension in the work done on ignition of coal dust by warm gases would also be in order.

It is observed that the bulk of the research work available, has been conducted under conditions that bear little relationship to the environment with which we are concerned. Future work should be directed to unit testing, of production equipment. For example starters could be run on long term cycle tests in explosive atmospheres. Similarly, future braking system research could be conducted using systems in cycle tests on dynamotors in explosive atmospheres.

ACKNOWLEDGEMENT

I am grateful to the many people who have given of their time and talent in assisting me in this project. In particular I would like to acknowledge the aid from the National Coal Board in the U.K. whose courtesy and co-operation were most commendable.

I would also like to say that all the manufacturers approached during this investigation were most candid and helpful.

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APPENDIX I

Catalogue Details on Typical Diesel Powered Equipment for Coal Mining Made By:

Hudswell-Badger Ltd.

Hunslet (Holdings) Ltd.

Envirotech Corp.

Wagner Mining Equipment Co.

Scharf

POOR

QUALITY

ORIGINAL